

Draft Chapter 5

MANAGING STORMWATER

5.0 INTRODUCTION: THE HISTORICAL REALITIES

The modern urban drainage system came into being soon after World War II. This generally consisted of a system of catch basins and pipes to prevent flooding and drainage problems by efficiently delivering runoff water to the nearest water body. However, as noted in **Chapter 4**, delivering the water too quickly often caused severe downstream flooding and streambank erosion in the receiving water. To prevent streambank erosion and provide more space for flood waters, some stream channels were enlarged and lined with concrete. While hardening and enlarging natural channels appeared to solve the erosion and flooding in the immediate vicinity, at some point the paved channels ended. The modified channels delivered increased peak flows to the unprotected receiving streams, often causing erosion and flooding further downstream and disturbing habitat necessary to support healthy aquatic ecosystems.

To control the quantity of water reaching the ends of pipes and channels during runoff events, on-site detention became the standard solution, requiring developers to reduce the peak flows of specified design storms. Detention can control peak flows directly below the point of discharge and at the property boundary. However, when designed on a site-by-site basis without taking other basins into account, they can lead to downstream flooding problems, because total flow volume is not reduced (McCuen, 1979; Ferguson, 1991; Traver and Chadderton, 1992; EPA, 2005d). In addition, in order to prevent clogging, openings in outlet structures for most basins are generally too large to hold back flows from smaller, more frequent storms – the storms that cause most of our water quality problems.

Because of the limitations of on-site detention, infiltration of urban runoff has become a recent goal of stormwater management, in order to control runoff volume. Without stormwater infiltration, Virginia communities can expect drops in local groundwater levels, declining stream base flows (Wang et al., 2003a), and flows diminished or stopped altogether from springs feeding wetlands and lakes (Leopold, 1968; Ferguson, 1994).

The need to provide volume control marked the beginning of Low Impact Development (LID) and Conservation Design (Prince George's County, 2000; Arendt, 1996), which were founded on the work of landscape architect Ian McHarg and associates decades earlier (McHarg and Sutton, 1975; McHarg and Steiner, 1998). The goal of LID is to allow for development of a site while maintaining as much of its natural hydrology as possible (e.g., infiltration, frequency and volume of discharges, and groundwater recharge). This is accomplished with infiltration practices, functional grading, open channels, disconnection of impervious areas, and the creation of less impervious surfaces. Much of the LID focus is to manage the stormwater as close as possible to its source – that is, on each individual lot rather, than conveying the runoff to a larger regional Stormwater Control Measure (SCM). Individual practices include rain gardens, disconnected roof drains, permeable pavement, narrower streets, and grass swales. In some cases, LID site plans still must include a method for passing the larger storms safely from the site and through the downstream drainage system.

Evidence gathered in the 1970s and 1980s suggested that pollutants be added to the list of things in stormwater that need to be controlled (EPA, 1983). Damages caused by elevated flows, such as stream habitat destruction and floods, were relatively easy to document with something as simple as photographs. However, documentation of elevated concentrations of conventional and potentially toxic pollutants required intensive collection of water quality samples during runoff events. Early sampling efforts clearly showed the concentration of many pollutants, such as heavy metals and sediment, were elevated in urban runoff (Bannerman et al., 1979). Levels of heavy metals were especially high in industrial site runoff, and construction erosion was calculated to be a large source of sediment in watersheds. The National Urban Runoff Program added more evidence about the high levels of some pollutants found in urban runoff (Athayde et al., 1983; Bannerman et al., 1983).

With new development rapidly adding to the environmental impacts of existing urban areas, the need to develop effective stormwater management programs is more urgent than ever. Current day SCMs represent a radical departure from past practices, which focused on dealing with extreme flood events via large detention basins designed to reduce peak flows at the downstream property line. As described in this chapter, SCMs now include practices intended to meet broad watershed goals of protecting the biology and geomorphology of receiving waters in addition to flood peak protection. Effective stormwater management encompasses such diverse actions as using more conventional practices, like basins and wetlands, as well as installing stream buffers, reducing impervious surfaces, reducing runoff volume, removing pollutants, and educating the public.

5.1 TODAY'S STORMWATER MANAGEMENT GOALS

It is difficult to discuss methods of controlling stormwater without first considering the goals those methods are expected to meet. A broadly stated goal for stormwater management is as follows: *To reduce pollutant loads to water bodies and maintain, as much as is possible, the natural hydrology of a watershed.* This goal is translated more specifically in the Virginia Stormwater Management Law, as follows:

. . . maintain after-development runoff rate of flow and characteristics that replicate, as nearly as practicable, the existing predevelopment runoff characteristics and site hydrology, or improve upon the contributing share of the existing predevelopment runoff characteristics and site hydrology if stream channel erosion or localized flooding is an existing predevelopment condition. (§ 10.1-603.4.7, Code of Virginia)

As is the case in numerous other states, Virginia relies on engineering criteria for SCM performance as the basis for more specific stormwater management goals. These criteria can be loosely categorized as:

Erosion and Sediment Control: This goal refers to the prevention of erosion and sedimentation from sites during construction and is focused at the site level. Criteria usually include a barrier plan to prevent sediment from leaving the site (e.g., silt fences, etc.), practices to minimize potential erosion of exposed soils (e.g., phased construction, timely stabilization, etc.), and

facilities to capture and remove sediment from runoff (e.g., sediment basins, etc.). Because these measures are considered temporary, smaller storm events are designated as the design storms rather than those typically used if flood control is the goal.

Recharge Groundwater and Stream Base Flow: This goal focuses on sustaining the pre-construction hydrology of a site as it relates to stream base flow and groundwater recharge.

Water Quality Protection: This goal is usually crafted as a percent removal or a quantitative load limit for one or more specific target pollutants typically present in the stormwater discharge, and the goal is usually associated with a set volume (“Treatment Volume”) of stormwater being treated by the SCMs. In Virginia, the target/indicator pollutant is Total Phosphorus.

Stream Channel Protection: This goal refers to protecting receiving stream channels from accelerated erosion during and immediately after storm events due to increased runoff. It is tied to the storm event that is presumed to be the typical “channel forming” storm event.

Frequent Flood Prevention: This goal addresses public safety and protection of property. It is applicable to storm events that exceed the carrying capacity of the receiving channel.

Extreme Flood Protection: This goal addresses public safety and protection of property in the event of an extreme or catastrophic storm event, such as the 100-year storm. In Virginia this goal addressed, as is typically done elsewhere, through flood plain management ordinances and BMP design criteria that provide for bypassing the extreme storm flow safely around stormwater control structures.

In Virginia, erosion and sediment control is the subject of a completely separate regulatory program. The other goals are discussed in more detail in **Chapter 10, *Unified Sizing Criteria***.

5.2 THE EMERGING SOLUTION

Some U.S. communities are already taking steps to successfully manage their land and develop using a more holistic, *green infrastructure* approach. Green infrastructure is our Commonwealth’s life support system – an interconnected network of waterways, wetlands, woodlands, wildlife habitats and other natural areas such as greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces. This green network supports native species, maintains natural ecological processes, sustains air and water resources, and contributes to the health and quality of life for Virginia’s communities and citizens (adapted from Benedict and McMahon, 2006). More simply, green infrastructure is a network of ecologically significant blocks of landscape, called cores or hubs, which connect to linear bands of green space, called corridors.

Green infrastructure planning is actually a comprehensive planning-scale approach that identifies these hubs and corridors, integrating outdoor recreation, open space, cultural resources and conservation lands. Strategically linking linear land corridors maximizes environmental, habitat and outdoor recreation resources to meet the needs of growing populations. The planning model identifies and ranks vital natural resources in concert with other community needs and gray

infrastructure prior to development. Land development and growth is then guided in ways that accommodate increased populations while protecting natural resources, thereby providing long-term economic viability and community sustainability.

While green infrastructure-type comprehensive planning is beyond the scope of this Handbook, it is important for site and stormwater designers to understand the natural linkages of this approach with site and stormwater design. The techniques of Environmental Site Design, which are discussed and recommended in this Handbook, promote preserving open space and sensitive resources and minimizing impervious cover. The open spaces preserved on a site provide more impact when they are linked with identified green infrastructure hubs and corridors to strengthen the green system. At the scale of SCM selection and design, focusing on runoff reduction carries this approach even further, to the micro-site scale, helping to replicate existing site hydrology and runoff characteristics, while minimizing negative impacts on the natural stream system that is part of our green infrastructure.

Emerging green design techniques for managing stormwater present a new pollution control philosophy based on the known benefits of natural systems, which provide multimedia pollution reduction and use soil and vegetation for the trapping, treating, filtration, infiltration and evapotranspiration of stormwater. The communities already using these techniques are finding that they provide a viable alternative to traditional stormwater management methods.

In addition to removing pollution from runoff, this more holistic approach reduces and delays runoff volumes, enhances groundwater recharge, protects surface water from stormwater runoff, increases carbon sequestration, mitigates urban heat island effects, improves air quality, increases wildlife habitat, and results in better urban aesthetics. In other words, *this approach more closely replicates the pre-development hydrology and runoff characteristics of the site*

Although used widely overseas, particularly in Germany and Japan, the use of this approach in the United States is still in its infancy. However, data indicate that it can effectively reduce stormwater runoff and remove stormwater pollutants. Communities that have implemented green design are already reaping the benefits.

The urban landscape, with its large areas of impermeable roadways and buildings (impervious surfaces) has significantly altered the movement of water through the environment. Over 100 million acres of land have been developed in the United States, and with development and sprawl increasing at a rate faster than population growth, urbanization's negative impact on water quality is a problem that won't be going away. To counteract the effects of urbanization, communities are beginning to promote site designs that intercept precipitation and allow it to infiltrate, rather than being collected on and conveyed from impervious surfaces.

Each year, the rain and snow that falls on urban areas in the United States results in billions of gallons of stormwater runoff and combined sewer overflows (CSOs). Green design techniques reduce the amount of pollution introduced into waterways and relieve the strain on stormwater and wastewater infrastructure. Efforts in many cities have shown that this approach can be used to reduce the amount of stormwater discharged or entering combined sewer systems and that it can be cost-competitive with conventional stormwater and CSO controls.

This new approach to site and stormwater design is also unique because it offers an alternative land development approach. New developments that incorporate these techniques often cost less to build because of decreased site development and conventional infrastructure costs. Furthermore, such developments are often more attractive to buyers because of environmental amenities. The flexible and decentralized qualities of this approach also allow it to be retrofitted into developed areas to provide stormwater control on a site-specific basis. The techniques can be integrated into redevelopment efforts ranging from a single lot to an entire citywide plan.

Nonetheless, wider adoption of this new design approach still faces obstacles. Among these is the economic investment that is required across the country for adequate stormwater and CSO control. Although these techniques are in many cases less costly than traditional methods of stormwater and sewer overflow control, some municipalities persist in investing only in existing conventional controls rather than trying an alternative approach. Local decision makers and organizations must take the lead in promoting a cleaner, more environmentally beneficial method of reducing the water pollution that affects their communities. The DCR recommends that local decision makers institute the following policies to promote the use of green infrastructure:

- 1. Develop with green design and pollution management in mind.** Build green space into new development plans and aim to preserve as much existing vegetation as is feasible.
- 2. Incorporate green design into long- term control plans for managing combined sewer overflows.** Green techniques can be incorporated into plans for infrastructure repairs and upgrades.
- 3. Revise local stormwater regulations to encourage green design.** A policy emphasis should be placed on reducing impervious surfaces, preserving vegetation, capturing runoff on-site, providing water quality improvements, and protecting receiving streams from runoff-related damage. (*NRDC – “Rooftops to Rivers”*)
- 4. Incorporate stormwater management, including environmental site design techniques that reduce imperviousness, in the early planning stages of development projects and community growth strategies.** Retrofitting existing development with SCMs is much more technically difficult and costly, because the space may not be available, other infrastructure is already installed, and/or utilities may interfere. There may also be easements dedicated to homeowner’s associations or other entities that present regulatory limitations to what can be done. Because of these kinds of barriers, retrofitting existing urban areas often depends on the use of engineered or manufactured SCMs, which are more expensive for both construction and operation (NRC, 2008).

In support of these concepts, the Water Science and Technology Board of the National Research Council has recently recommended that “[f]uture development and water resource protection plans should consider reducing impervious cover in the potential expansion of communities” (NRC, 2008, pg. 119). Examples of this include encouraging residential cluster developments, building taller buildings, reducing the width of residential streets, creating one-side sidewalks, reducing the size of parking lots to satisfy average parking needs rather than peak requirements, and using permeable pavement in overflow parking lots. In so doing, traditional impervious cover could be reduced 10-50 percent (NRC, 2008, pg. 122).

5.2.1 What Is the Green Infrastructure Approach?

In the *green infrastructure* approach, centralized treatment and/or storage facilities located at the “end of pipe” discharge from developed sites are classified as structural SCMs. While structural SCMs such as stormwater ponds and wetlands can be effective in controlling peak flows from the site, current regulatory requirements for these structures do not address the frequent storms that erode stream banks, and do little or nothing to promote recharge. Furthermore, structural SCMs can contribute to downstream flooding when discharges from separate on-site structural SCMs overlap. Structural SCMs can be effective in pollutant removal; but since they generally omit groundwater recharge, consume space, and require extensive maintenance, they are less appropriate for the task. There is an emerging recognition that wet detention structural SCMs contribute to elevated stream temperatures, and discharge algae laden effluent, which can substantially degrade the benthic community in the receiving stream.

As a result, many progressive agencies are promoting the green infrastructure approach, which is designed to intercept runoff from rooftops, parking lots and roads as close as possible to its source, and direct it into vegetative recharge/filtration facilities incorporated into the overall site design and runoff conveyance system. Green infrastructure design techniques described in this Handbook include environmental site design, impervious area disconnection, conveyance of runoff through filter strips and swales, terraces, bioretention facilities, and recharge through infiltration facilities. These SCMs form the basis of green infrastructure at the site engineering level.

Since these vegetated structures do not rely on detention, these SCMs are “Green”. However, while green infrastructure SCMs may seem less complex than structural detention measures, procedures for their proper design require the same hydrologic and hydraulic methods used in designing structural SCMs. The use of green design also involves a quantitative approach for reducing runoff volume and estimating pollutant loads, as well as projecting how well a particular design will remove such pollutants. Hence it is a “Technology”, capable of providing realistic estimates of pollutant loading and removal, while also addressing hydrologic and hydraulic parameters involved in urban site design.

5.2.2 The Treatment Train Approach

Many, if not most, development sites will need to employ multiple practices in order to satisfy the nutrient reduction requirements in the Regulations and adequately manage stormwater runoff. Under the treatment train approach, stormwater management begins at the site level with simple methods that (1) minimize the amount of runoff from the site, and (2) prevent pollution from accumulating on the land surface and becoming available for transport in site runoff. This approach relies heavily on Better/Environmental Site Design, pollution source controls, and non-structural SCMs). **Figure 5.1** illustrates this “treatment train” approach.

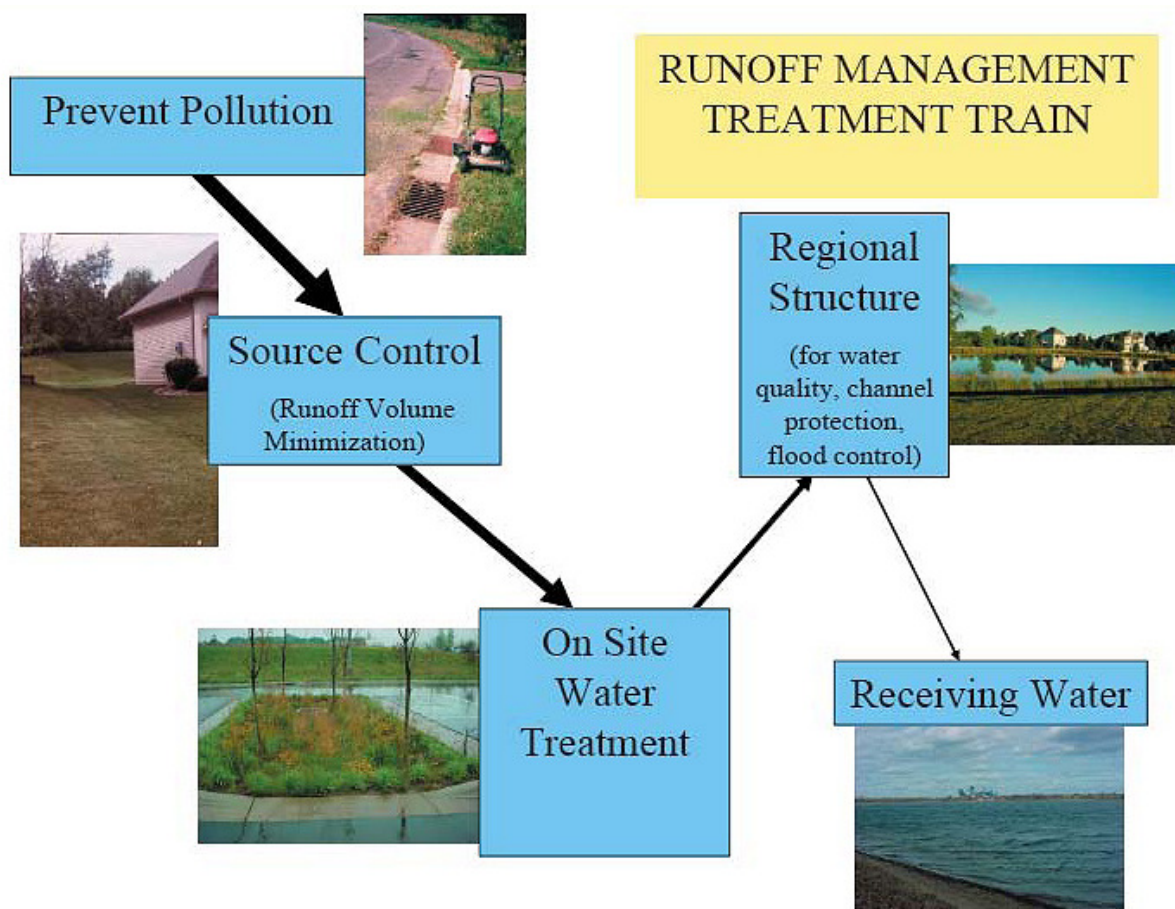


Figure 5.1: Treatment Train Approach for Stormwater Management (MPCA, 2005)

As noted above, to be most effective and least costly, stormwater management plans should be conceived in the early planning stages of development projects. Most important, stormwater management plans using the green infrastructure approach organize the SCMs in a way that mimics the natural hydrology of the site. Thus, rainfall travels from the roof to the stream through a series of practices spread throughout the entire development site. **Table 5.1** lists groups of practices that reflect this order. No SCM should be considered for use without first considering those that precede it on this list. For example, environmental site design techniques, such as conserving or restoring open space and natural areas or minimizing impervious coverage through narrower streets, clustering, etc. are the first step. At this stage, pollution prevention practices are also applied to minimize the amount of pollutants that are available to wash off the site in stormwater runoff.

Then initial capture practices are applied, such as green roofs, rainwater harvesting (rain tanks and cisterns), or downspout disconnection are applied. Remaining runoff would then be directed to practices such as grass filters or dry swales, which might drain into bioretention or infiltration structures. This approach minimizes the amount of runoff generated and captures much of the runoff along the pathway to the development site outfall. If additional treatment or volume mitigation is needed, a pond or constructed wetland might be installed at the downstream end of the development site, as the final practice in the treatment train.

As noted above, these measures often result in significant cost savings for development projects, even when land costs are factored. Once efforts to minimize runoff volume and stormwater pollution are identified, the next step is to select structural stormwater SCMs, or groups of SCMs, aimed at collecting and treating the runoff that is generated.

The following provides additional information about each step in the treatment train approach to SCM selection. Included in the discussion are examples of some of the different structural and non-structural SCMs that can be employed during each step of the SCM selection process at a development site.

5.2.2.1 Pollution Prevention

The first step in effectively managing stormwater is to identify opportunities for stormwater pollution prevention. Non-structural SCMs can be employed to minimize the amount of runoff and the risk of stormwater pollution to the greatest extent possible. The implementation of pollution prevention practices involves looking for opportunities to reduce the exposure of pollutants to rainfall and runoff at the development site. Examples include keeping impervious surfaces clean and handling and storing chemicals properly.

The pollution prevention practices that can be used depend on whether the land use is residential, commercial, industrial, institutional, or municipal development. The nature and distribution of pollutant sources are different at every development site and, therefore, the practices that are used are unique to each site... **Table 5.2** illustrates some of the common pollution prevention practices used in both residential and non-residential developments.

Table 5.1. Summary of Stormwater Control Measure Categories

Stormwater Control Measure	When	Where	Who	Hydrologic Control Objectives	Water Quality Objectives	Est. Maint. Protocols
<i>1. Product Substitution (lead-free gasoline, ethanol, P-free detergent, etc.)</i>	Continuous	State, regional	Regulatory agencies	NA	Prevention	NA
<i>2. Watershed and Land-Use Planning</i>	Planning stage	Watershed	Local planning agencies	All objectives	Prevention	Yes
<i>3. Conservation of Natural Areas</i>	Site and watershed planning stage	Site, watershed	Developer, local planning agency	Prevention	Prevention	Yes
<i>4. Impervious Cover Minimization</i>	Site planning stage	Site	Developer, local review authority	Prevention & reduction	Prevention	No
<i>5. Earthwork Minimization</i>	Grading plan	Site	Developer, local review authority	Prevention	Prevention	Yes
6. Erosion and Sediment Control	Construction	Site	Developer, local review authority	Prevention & reduction	Prevention and removal	Yes
<i>7. Reforestation and Soil Conservation</i>	Site planning and construction	Site	Developer, local review authority	Prevention & reduction	Prevention	No
<i>8. Pollution Prevention SCMs for Stormwater Hotspots</i>	Post-construction or retrofit	Site	Operators and local and state permitting agencies	NA	Prevention	No
9. Runoff Volume Reduction – Rainwater Harvesting	Post-construction or retrofit	Rooftop	Developer, local planning agency and review authority	Reduction	Removal	Yes
10. Runoff Volume Reduction – Vegetated (Green roofs, Bioretention, Bioinfiltration, Bioswales)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	Reduction & some peak attenuation	Removal	Emerging
11. Runoff Volume Reduction – Subsurface (Infiltration Trenches, Permeable Pavement)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	Reduction & some peak attenuation	Removal	Yes
12. Peak Reduction and Runoff Treatment (Stormwater Wetlands, Dry/E.D. Ponds)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	Peak attenuation	Removal	Yes
13. Runoff Treatment (Sand Filters, Manufactured Treatment Devices)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	None	Removal	Yes
<i>14. Aquatic Buffers and Managed Floodplains</i>	Planning, construction and post-construction	Stream corridor	Developer, local planning agency and review authority, landowners	NA	Prevention and removal	Emerging
15. Stream Rehabilitation	Post-development	Stream corridor	Local planning agency and review authority	NA	Prevention and removal	Unknown
<i>16. Municipal Housekeeping (Street Sweeping, Storm Drain Cleanouts)</i>	Post-development	Streets and stormwater infrastructure	MS4 permittee	NA	Removal	Emerging
<i>17. Illicit Discharge Detection and Elimination</i>	Post-development	Stormwater infrastructure	MS4 permittee	NA	Prevention and removal	No
<i>18. Stormwater Education</i>	Post-development	Stormwater infrastructure	MS4 permittee	Prevention	Prevention	Emerging
<i>19. Residential Stewardship</i>	Post-development	Stormwater infrastructure	MS4 permittee	Prevention	Prevention	No
NOTES: 1 - Nonstructural SCMs are listed in italics. 2 - NA = Not applicable for the SCM. 3. – Shaded rows correspond to the Runoff Reduction Method and Practices shown in Table 5.5.						
When		Where		Who		
At which stage of the development cycle is the practice applied?		Location/scale in the site/watershed where the practice is installed?		Who is responsible for implementing the practice?		

Hydrologic Objective	Water Quality Objective	Defined Maintenance Protocol?
Prevention = prevents generation of runoff Reduction = reduces volume of runoff Treatment = delays runoff delivery only Peak Attenuation = reduction of peak flows through detention	Prevention = prevents generation, accumulation, or wash-off of pollutants and/or reduces runoff volume Removal = reduces pollutant concentrations in runoff by physical, chemical or biological means	No = extremely limited understanding of procedures to maintain SCM in the future Emerging = still learning about how to maintain the SCM Yes = solid understanding of maintenance for future SCM needs

Source: Adapted from NRC, 2008

Table 5.2. Common Pollution Prevention Practices (Source Controls)

Residential Developments	Non-Residential Developments
<ul style="list-style-type: none"> • Product Substitution • Natural Landscaping • Tree Planting • Yard Waste Composting • Septic System Maintenance • Driveway Sweeping • Street Sweeping • Household Hazardous Waste Collection Programs • Car Fluid Collection and Recycling Programs • Downspout Disconnection • Pet Waste Pickup • Storm Drain Marking 	<ul style="list-style-type: none"> • Covered Loading Areas • Covered Fuel Containment Areas (p.h.) • Covered Vehicle Storage Areas • Storm Drain Disconnection • Downspout Disconnection • Street Sweeping • Covered Dumpsters • Covered Materials Storage Areas • Secondary Containment Structures • Spill Response Plans • Signage • Employee Training

A good resource for more specific guidance about pollution prevention measures is the Manual #9 of the Center for Watershed Protection's *Urban Subwatershed Restoration Manual Series*, entitled *Municipal Pollution Prevention / Good Housekeeping Practices* (June 2008). The USEPA web site is also a good source for guidance on many of these source control types of practices, at:

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=6

5.2.2.2 Runoff Volume Reduction

The next step in effectively managing stormwater is to identify opportunities for runoff volume reduction and/or groundwater recharge at the development site, which can reduce the generation of stormwater runoff. These SCMs typically have the effect of reducing the amount of impervious cover and the amount of stormwater runoff that must be controlled, which can save space and reduce the cost of SCMs at the site. **Table 5.3** lists some of the common SCMs used to reduce runoff volumes at development sites. **Figure 5.2** is an example of a Green Street design, incorporating several of these concepts. This location, part of the Natural Drainage Systems Project in Seattle, Washington, exhibits several elements of impervious cover reduction. In particular, vegetated swales were installed and curbs and gutters removed. There are sidewalks on only one side of the street, and they are separated from the road by the swales. The residences' rooftops have been disconnected from the storm drain systems and are redirected into the swales. **Figure 5.3** is a cluster development that conserves natural open space for common use and reduces the amount of streets and utilities needed to serve the community.

Table 5.3: Common Stormwater Control Measures Used to Reduce Runoff Volume

Runoff Reduction SCMs	
<ul style="list-style-type: none"> • Natural Area Conservation • Site Reforestation • Prairie/Meadow Restoration • Stream and Shoreline Buffers • Soil Amendments • Impervious Cover Disconnection • Downspout Disconnection • Open Space Subdivision • Design Grass Channels • Bioretention 	<ul style="list-style-type: none"> • Filtration • Infiltration • Dry Swales • Filter Strips (Sheet Flow to Open Space) • Reduced Street Width • Reduced Sidewalks • Smaller and/or Vegetated Cul-de-sacs • Shorter Driveways • Green Parking Lots and Driveways • Shared Parking Lots and Driveways



Figure 5.2. Green Street Design for 110th Street, Seattle, WA
 (Source: Seattle Public Utilities)

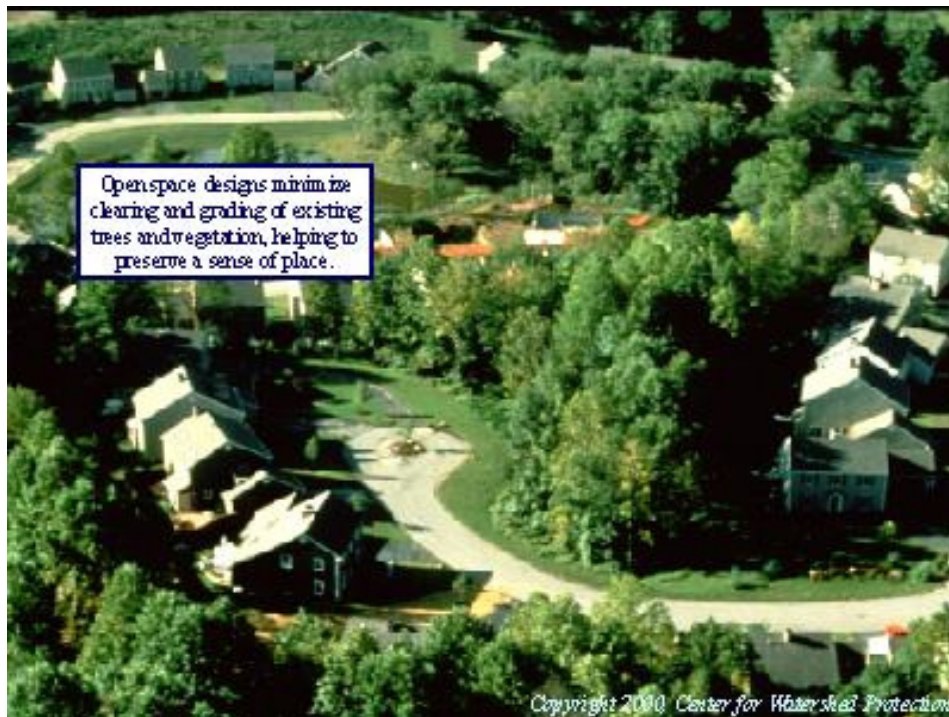


Figure 5.3. Cluster Development

In the past, using these kinds of site design techniques, such as preserving open space to reduce runoff volume, did not translate into any kind of economically tangible credit for developers in Virginia. However, that is no longer true. Runoff volume calculations using the new Runoff Reduction Method (discussed below) will generate smaller amounts of site runoff where land cover is preserved that produces less runoff. This will translate into fewer and/or smaller SCMs needed on the site to manage the runoff. **Chapter 6** will provide more specific guidance about Environmental Site Design techniques.

5.2.2.3 On-Site and Off-Site Structural Stormwater Treatment

The final step in managing site stormwater effectively is to select individual structural stormwater SCMs, or groups of structural SCMs, aimed at collecting and treating runoff either on-site or off-site. These structural SCMs include:

- Runoff Volume Reduction (including Vegetated Roofs and Rainwater Harvesting)
- Grass Swales or Open Channels (including Dry Swales and Wet Swales)
- Filtration (including Filters and Biofiltration)
- Infiltration (including Permeable Pavement and Bioinfiltration)
- Stormwater Basins (Constructed Wetlands, Wet ponds, and Extended Detention)

5.2.2.4 Use of Proprietary SCMs

There is a plethora of proprietary and experimental stormwater technologies on the market. Adding these practices to the list provides designers with more flexibility to comply with stormwater requirements in difficult development situations. On the other hand, the performance of many of these products still remains largely unproven, and their real world maintenance burden is largely unknown. In addition, many vendors make extravagant claims about performance and can be very aggressive about getting their products added to the list of SCMs approved for use. The DCR, in cooperation with the Virginia Water Resource Research Center at Virginia Tech, has established a process for evaluating and certifying manufactured treatment devices (MTDs) for use in the state. A list of approved MTDs, at several levels of certification, is provided on the Virginia Stormwater BMP Clearinghouse web site, at <http://www.vwrrc.vt.edu/swc/>.

5.3 THE VIRGINIA APPROACH

5.3.1 Site-Based Nutrient Load Limits

The Runoff Reduction Method for Virginia is focused on site compliance to meet a site-based load limit for Total Phosphorus (TP) of 0.28 lbs./acre/year. This means that the proposed Virginia stormwater regulations are aimed at limiting the total load of Phosphorus leaving a new development site. This is a departure from water quality computations of the past, in which the analysis focused on comparing the post-development site condition to the pre-development condition, or an average land cover condition. The chief objective of instituting a site-based load limit is so that land, as it develops, can still meet the nutrient reduction goals outlined in the Chesapeake Bay Tributary Nutrient Reduction Strategies.

With the site-based limit, newly-developed land will maintain loadings that replicate existing loading from agricultural, forested and mixed-open land uses, where there is no impervious cover. This is not to say that all developing parcels will maintain the pre-development loading rates, but that the rates, averaged across all development sites, will not increase when compared with loading rates from non-urban land.

An operational advantage to using site-based load limits is that it simplifies computations by focusing on the post-development condition. This should reduce time-consuming conflict between site designers and local government plan reviewers by eliminating disagreements about how to characterize the pre-development condition for a particular site.

The load limit calculations for the proposed Virginia stormwater regulations were performed by Virginia DCR staff, based on model outputs from the U.S. EPA Chesapeake Bay Program Watershed Model Scenario Output Database (Phase 4.3) (Commonwealth of Virginia, 2005). The DCR calculations led to a proposed load limit of 0.28 pounds/acre/year for Total Phosphorus. DCR has concluded that, by using the array of updated SCM designs provided on the Stormwater BMP Clearinghouse web site, site designers should also accomplish most (if not all) of the Tributary Strategy target reductions of Total Nitrogen (TN) from developing lands. The DCR calculations led to a proposed load limit of 2.68 pounds/acre/year for TN, even though that limit is not specified as a compliance requirement in the regulations.

5.3.2 Runoff Coefficients – Moving Beyond Impervious Cover

The negative impacts of increased impervious cover (IC) on receiving water bodies have been well documented (CWP 2003, Walsh et al. 2004; Shuster et al. 2005; Bilkovic et al. 2006). Due to widespread acceptance of this relationship, IC has frequently been used in watershed and site design efforts as a chief indicator of stormwater impacts.

More recent research, however, indicates that other land covers, such as disturbed soils and managed turf, also impact stormwater quality (Law et al, 2008). Numerous studies have documented the impact of grading and construction on the compaction of soils, as measured by increase in bulk density, declines in soil permeability, and increases in the runoff coefficient (OCSCD et al, 2001; Pitt et al, 2002; Schueler and Holland, 2000). These areas of compacted pervious cover (lawn or turf) have a much greater hydrologic response to rainfall than forest or pasture.

Further, highly managed turf can contribute to elevated nutrient loads. Typical turf management activities include mowing, active recreational use, and fertilizer and pesticide applications (Robbins and Birkenholtz 2003). An analysis of Virginia-specific data from the National Stormwater Quality Database (Pitt et al. 2004) found that runoff from monitoring residential sites with relatively low IC contained significantly higher nutrient concentrations than sites with higher IC non-residential uses (CWP & VA DCR, 2007). This suggests that residential areas with relatively low IC can have disturbed and intensively managed pervious areas that contribute to elevated nutrient levels.

The failure to account for the altered characteristics of disturbed urban soils and managed turf can result in an underestimation of stormwater runoff and pollutant loads generated from urban pervious areas. Therefore, Virginia's new Runoff Reduction Method, the computation procedure for complying with the nutrient reduction requirements in the regulations, accounts for both impervious cover and other important land cover types. The runoff coefficients provided in **Table 5.4** were derived from research by Pitt et al (2005), Lichter and Lindsey (1994), Schueler (2001a), Schueler, (2001b), Legg et al (1996), Pitt et al (1999), Schueler (1987) and Cappiella et al (2005). As shown in this table, the effect of grading, site disturbance, and soil compaction greatly increases the runoff coefficient compared to forested areas.

Table 5.4. Site Cover Runoff Coefficients (R_v)

Soil Condition	Runoff Coefficient
Forest Cover	0.02 to 0.05*
Disturbed Soils/Managed Turf	0.15 to 0.25*
Impervious Cover	0.95
*Range dependent on original Hydrologic Soil Group (HSG), as follows: For Forest: A = 0.02; B = 0.03; C = 0.04; and D = 0.05 For Disturbed Soils: A = 0.15; B = 0.20; C = 0.22; and D = 0.25	

5.3.3 Treatment Volume – The Common Currency for Site Compliance

Treatment Volume (Tv) is the central component of the Runoff Reduction method. By applying site design, structural, and nonstructural practices, the designer can reduce the treatment volume by reducing the overall volume of runoff leaving a site. In this regard, the Treatment Volume is the main “currency” for site compliance.

As explained more fully in **Chapter 10, *Unified Sizing Criteria***, Treatment Volume is a variation of the 90% capture rule that is based on a regional analysis of the mid-Atlantic rainfall frequency spectrum. In Virginia, the 90th percentile rainfall event is defined approximately as one-inch of rainfall.

The rationale for using the 90th percentile event is that it represents the majority of runoff volume on an annual basis. Larger events would be very difficult and costly to control for the same level of water quality protection (as indicated by the upward inflection at 90%). However, by controlling the 1-inch rainfall event, these larger storm events would also receive partial treatment for water quality, as well as storage for channel protection and flood control.

The proposed Treatment Volume (Tv) has several distinct advantages when it comes to evaluating runoff reduction practices and sizing BMPs:

- The Tv provides effective stormwater treatment for approximately 90% of the annual runoff volume from the site, and larger storms will be partially treated.
- Storage is a direct function of impervious cover and disturbed soils, which provides designers incentives to minimize the area of both at a site.
- Using the 90% storm event to define the Tv is widely accepted and is consistent with other state stormwater manuals (MDE, 2000, ARC, 2002, NYDEC, 2001, VTDEC, 2002, OME, 2003, MPCA, 2005).
- The Tv approach provides adequate storage to treat pollutants for a range of storm events. This is important since the first flush effect has been found to be modest for many pollutants (Pitt et al 2005).
- Tv provides an objective measure to gage the aggregate performance of environmental site design, LID and other innovative practices, and conventional BMPs together using a common currency (runoff volume).
- Calculating the Tv explicitly acknowledges the difference between forest and turf cover and disturbed and undisturbed soils. This creates incentives to conserve forests and reduce mass grading and provides a defensible basis for computing runoff reduction volumes for these actions.

5.3.4 The Runoff Reduction Method

At the core of Virginia's green infrastructure approach to stormwater management is a new *Runoff Reduction (RR) Method*, developed with assistance from the Center for Watershed Protection and the Chesapeake Stormwater Network. This methodology was developed in order to promote better stormwater design and as a tool for compliance with the Virginia Stormwater Management Regulations. There are several shortcomings to existing stormwater design practices that the Runoff Reduction Method seeks to overcome, as follows:

- **Leveling the SCM Playing Field:** The suite of SCMs that has been available up to now in Virginia has been somewhat limited. There are many new and innovative practices that have proven effective at reducing runoff volumes and pollutant loads. In particular, good site design practices, that reduce stormwater impacts through design techniques, are not “credited” in the existing system. The RR Method puts traditional and innovative BMPs on a level playing field in terms of SCM selection and site compliance.
- **Meeting the Big-Picture Goals:** The existing stormwater compliance system does not meet Chesapeake Bay Tributary Strategy nutrient reduction goals for urban land. As sites are developed, the nutrient loads from urban land increase at a rate that exceeds urban land targets. The RR Method uses better science and improved SCM specifications to help with the job of incrementally attaining the Tributary Strategy goals for phosphorus and nitrogen.
- **Moving Beyond Addressing Only Impervious Cover:** Previous computation procedures used impervious cover as the sole indicator of a site's water quality impacts. More recent research indicates that a broad range of land covers – including forest, disturbed soils, and managed turf – are significant indicators of water quality and the health of receiving streams. The RR Method accounts for these land covers and provides built-in incentives – those credits that were not previously available – to protect or restore forest cover and reduce impervious cover and disturbed soils.
- **Moving Towards Total SCM Performance:** The previous system for measuring SCM effectiveness was based solely on the pollutant removal functions of the SCM, but did not account for the SCM's ability to reduce the overall volume of runoff. Recent research has shown that SCMs are quite variable in terms of providing runoff reduction, and some achieve very positive results. Runoff reduction has benefits beyond pollutant load reductions. SCMs that reduce runoff volumes can do a better job of replicating pre-development hydrologic conditions, protecting downstream channels, recharging groundwater, and, in some cases, reducing overbank (or “nuisance”) flooding conditions. The RR Method uses recent research on runoff reduction to better gauge total SCM performance.
- **Providing Accountability for Design:** Previously, it could be difficult for site designers and plan reviewers to verify SCM design features – such as sizing, pretreatment, and vegetation – that should be included on stormwater plans in order to achieve a target level of pollutant removal. Clearly, certain SCM design features either enhance or diminish overall pollutant removal performance. The RR Method provides clear guidance that links design features with performance by distinguishing between “Level 1” and “Level 2” designs.

As noted above, the RR Method relies on a three-step compliance procedure, as follows:

- **Step 1: Apply Site Design Practices to Minimize Impervious Cover, Grading and Loss of Forest Cover.** This step focuses on implementing Environmental Site Design (ESD) practices during the early phases of site layout. The goal is to minimize impervious cover and mass grading, and to maximize retention of forest cover, natural areas and undisturbed soils (especially those most conducive to landscape-scale infiltration). The RR Method uses a spreadsheet to compute a composite runoff coefficient for forest, disturbed soils, and impervious cover and to calculate a site-specific target treatment volume and Phosphorus load reduction target, based on criteria in the Virginia Stormwater Management Regulations.
- **Step 2: Apply Runoff Reduction (RR) Practices.** In this step, the designer considers possible combinations of RR practices on the site. In each case, the designer estimates the area to be treated by each RR practice to incrementally reduce the required treatment volume for the site. The designer is encouraged to use RR practices in series (i.e., *treatment trains*) within individual drainage areas (e.g., rooftop disconnection to a grass swale to a bioretention area) in order to achieve a higher level of runoff reduction.
- **Step 3: Compute the Pollution Removal (PR) of the Selected SCMs.** In this step, the designer uses the spreadsheet tool to see whether the required phosphorus load reduction has been achieved by the application of RR practices.
- **Step 4:** If the target phosphorus load limit is not reached, the designer can select additional SCMs that provide no runoff reduction but only treatment (e.g., filtering practices, wet ponds, stormwater wetlands, etc.) to meet the remaining load reduction requirement.

In reality, the process is *iterative* for most sites. When compliance cannot be achieved on the first try, designers can return to prior steps to explore alternative combinations of Environmental Site Design, Runoff Reduction practices, and Pollutant Removal practices to achieve compliance.

A **possible Step 5** would involve paying an offset fee (or fee-in-lieu payment) or providing off-site mitigation, where such options are provided for by the local stormwater management program, to compensate for any load that cannot feasibly be met on a particular site. The local government or program authority would need to have a watershed or regional planning structure for stormwater management in order to make these options available for sites within the jurisdiction. The amount of the fee would be based on the phosphorus “deficit” – that is, the difference between the target reduction and the actual site reduction after the designer makes his or her best effort to apply Runoff Reduction and Pollutant Removal practices.

Common sense indicates that well-maintained and high quality long-term records of precipitation are “vital and nontrivial” for effective stormwater management programs. A network of precipitation gauge data is available online from the National Climatic Data Center, at <http://www.ncdc.noaa.gov/oa/ncdc.html>, or the Cooperative Weather Observer Program, at <http://www.nws.noaa.gov/om/coop/>. Additionally, the National Weather Service provides estimates of the return periods for a range of depth-duration storm events, available at <http://www.nws.noaa.gov/om/coop/>. Considering the implications of climate change discussed in

Chapter 4, such that precipitation regimes are systematically being altered, it is paramount to update depth-duration-frequency curves in order to guarantee stormwater management facilities will be able to accommodate more intense precipitation.

Figure 5.4 is a flow chart illustrating the step-wise compliance process described above. **Table 5.5** includes a list of site design and stormwater practices that can be used for each step.

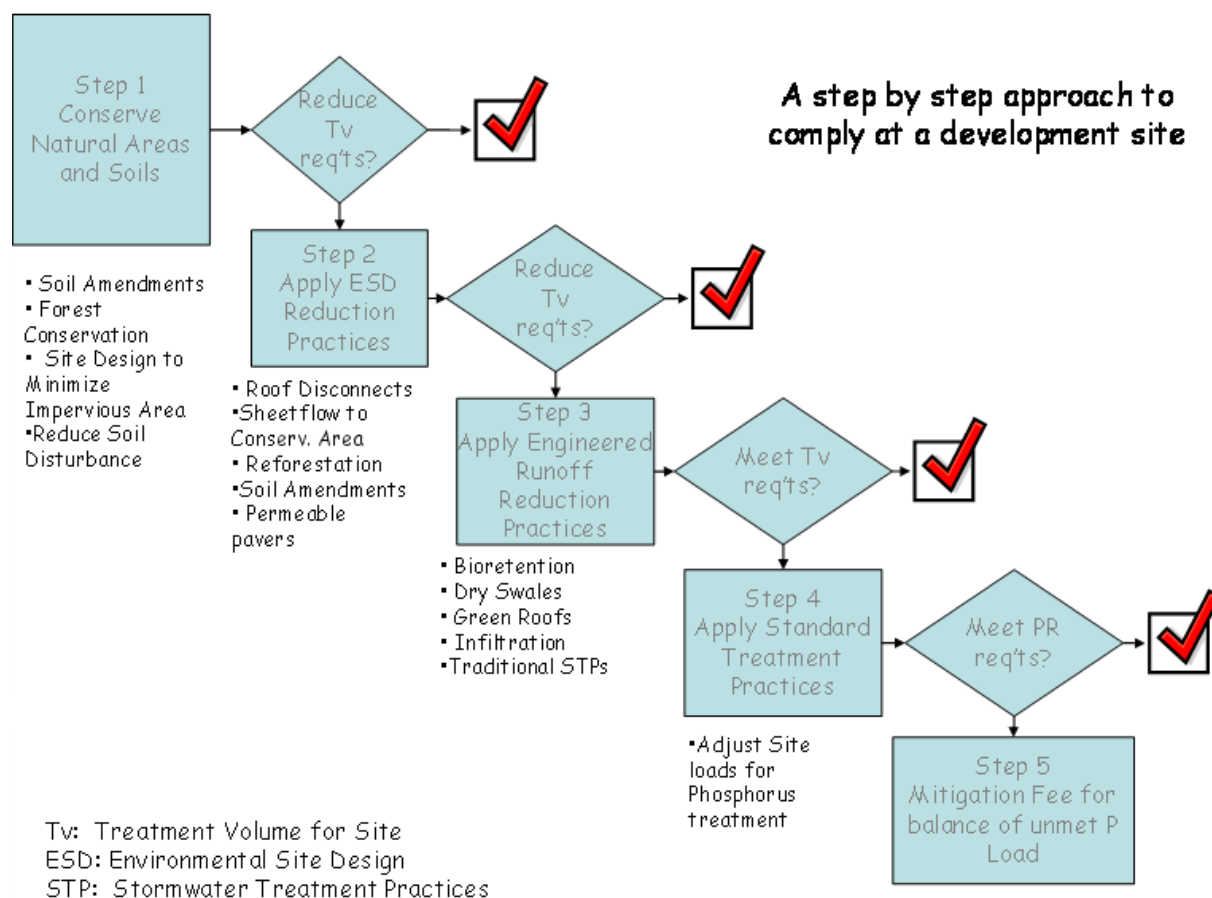


Figure 5.4. Step-Wise Process for Site Compliance

Table 5.5. Practices Included in the Runoff Reduction Method

Step 1: Environmental Site Design (ESD) Practices (see SCM 7 in Table 5.1)	Step 2: Runoff Reduction (RR) Practices (see SCMs 9-11 in Table 5.1)	Step 3: Pollutant Removal (PR) Practices (see SCMs 12-13 in Table 5.1)
Forest Conservation	Filter Strip (Sheet Flow to Conserved Open Space)	Filtering Practice
Site Reforestation	Rooftop Disconnection:	Constructed Wetland
Soil Restoration (combined with or separate from rooftop disconnection)	<ul style="list-style-type: none"> • Simple • To Soil Amendments • To a Rain Garden or Dry Well • To a Rain Tank or Cistern 	Wet Swale
Site Design to Minimize Impervious Cover and Soil Disturbance	Vegetated roof	Wet Pond
	Grass Channels	
	Permeable Pavement	
	Bioretention	
	Dry Swale (Water Quality Swale)	
	Infiltration	
	Extended Detention (ED) Pond	
NOTE: Practices in shaded cells achieve both Runoff Reduction (RR) and Pollutant Removal (PR) functions, and they can be used for Steps 3 and 4 depicted in Figure 5.1.		

5.4 STORMWATER CONTROL ON A WATERSHED SCALE

Implementing stormwater management on a site-by-site basis is the traditional mode of compliance in Virginia. This is largely due to the system of Land Use Law in Virginia, which vests authority for land use planning and decision-making with local governments. The reality is that few local governments have been willing to spend the money and perform the studies needed to support watershed-wide approaches to stormwater management, even though the Stormwater Management Law encourages and provides incentives to do so. Comprehensive watershed-scale stormwater management plans provide the most efficient and flexible means of continuing to develop sensibly while still meeting stormwater regulatory criteria. The traditional site-by-site approach has created a large number of individual stormwater management systems and SCMs that are widely distributed and have become a substantial part of the contemporary urban and suburban landscape.

The problem with the traditional approach is that the facilities are not designed to work as a *system* on a watershed scale. As a watershed is gradually built out, an unplanned system of site-based SCMs can actually increase flooding and channel erosion on a watershed scale, due to the effect of many facilities discharging into a receiving water body in an uncoordinated manner – causing the very problems the individual SCMs were built to prevent.

Stormwater management is most effectively undertaken in the context of a watershed management plan, with lower life-cycle costs to all involved. A watershed management plan is a comprehensive framework for applying management tools in a manner that achieves the water resource goals for the watershed as a whole (CWP, 1998a). Typically, watershed management plans are developed from watershed studies undertaken by one or more municipalities located within the watershed. The watershed approach has emerged over the past decade as the

recommended approach for addressing nonpoint source pollution problems, including polluted stormwater runoff. Watershed planning offers the best means to:

- Address cumulative impacts derived from a number of new land development projects;
- Plan for mitigation to address cumulative impacts from existing developments;
- Focus efforts and resources on identified priority water bodies and pollutant sources in a watershed; and
- Achieve noticeable improvements to impaired waters or waters threatened with impairment.

In this context, the term “watershed scale” refers to a small local watershed to which the individual site drains (i.e., a few square miles within a single municipality). Ideally, stormwater management should occur on a watershed scale to prevent flow control problems from occurring or reducing the chances that they might become worse.

The watershed approach is built on **three main principles**:

- First, the target watersheds should be those where stormwater impacts pose the greatest risk to human health, ecological resources, desirable uses of the water, or a combination of these issues.
- Second, parties with a stake in the specific local situation (i.e., stakeholders) should participate in the analysis of problems and the creation of solutions, creating significant “buy in” from those affected.
- Third, the actions undertaken should draw on the full range of methods and tools available, integrating them into a coordinated, multi-organization attack on the problems.

Watershed stormwater design can optimize the number, size and location of SCMs and result in more manageable long-term operation and maintenance of these facilities. Such an approach allows the developer, designer, plan reviewer, owners and the municipality to jointly participate in master planning and installation and operation of a linked and shared system of distributed practices across multiple sites that achieve small watershed-specific objectives, such as flood protection, stream protection and restoration, and water quality.

Furthermore, stormwater systems designed on a watershed basis are more likely to be perceived by local citizens as a multi-functional resource that can contribute to the overall quality of the urban environment. Potential even exists to make the stormwater system a primary component of the civic framework of the community – elements of the public realm that serve to enhance a community’s quality of life , such as public spaces, greenways and parks.

5.4.1 Watershed Planning Flexibilities in the Virginia Stormwater Management Regulations

Although site-by-site compliance with stormwater management requirements is much better than no stormwater management at all, evidence from across the nation indicates that individual controls on stormwater discharges are inadequate as the sole solution for stormwater in urban watersheds. SCM implementation needs, ideally, to be designed as a system, integrating structural and nonstructural SCMs and incorporating watershed goals, site characteristics, development land

use, construction erosion and sediment controls, aesthetics, monitoring and maintenance.

Stormwater cannot be adequately managed on a piecemeal basis due to the complexity of both the hydrologic and pollutant processes and their effect on habitat and stream quality.

Section 4 VAC 50-60-96 of the regulations allows local governments to develop comprehensive watershed-based stormwater management plans as an alternative way to comply with the water quality requirements, the water quantity requirements, or both. State and federal agencies intending to develop large tracts of land also may develop or participate in comprehensive watershed stormwater management plans where practicable. Section 4 VAC 50-60-76 also allows linear development projects, such as streets and highways, to achieve compliance in accordance with such a watershed plan, as an alternative to strictly on-site compliance.

Those who develop such plans must demonstrate to DCR and the Virginia Soil and Water Conservation Board that the results of implementing the plan will be at least as good as, if not better than, those that would be achieved from straightforward implementation of the regulation requirements on a site-by-site basis. The Board must approve local watershed plans before they may be implemented. The local program must document nutrient reductions achieved during the plan's implementation, in order to demonstrate the actual equivalence of compliance results. If the percent of impervious area upon which the plan was based changes or if any other amendments are deemed necessary by the local program, the local program must provide plan amendments to the Soil and Water Conservation Board for review and approval. For example, if the plan's target total nutrient removal for the watershed is based on an expected build-out resulting in a composite 53 percent impervious cover, and subsequently the locality approves comprehensive plan and zoning changes that will result in a composite 65 percent imperviousness at build-out, then the plan's original targets will not longer achieve results equivalent to those required in the regulations. The locality would need to amend the plan to achieve equivalence and submit the amendments to the Board for review and approval.

Section 4 VAC 50-60-63 of the regulations allows watershed plans to allow for compliance offsets (off-site mitigation, compliance trading, or fee-in-lieu options), where compliance is not feasible or cost-effective on the development site due to physical constraints, etc. In such cases, the chosen offset measure must ensure that the resulting stormwater control is equal to or greater than what would be required on each contributing land disturbing site. In fact, since the watershed planning process accounts for ultimate pollutant load reductions, such plans provide the best opportunity to optimize the most cost-effective strategy and mix of practices to achieve compliance. The regulations require that offsets must be achieved within the same Hydrologic Unit Code (HUC) watershed, or within HUCs established by the locality for this purpose. Watershed plans also provide the best opportunity for communities to achieve an effective approach to encouraging and stimulating redevelopment and infill development and discourage continued sprawl into outlying areas.

5.4.2. Virginia Examples of Using a Watershed Approach for Stormwater Management

5.4.2.1 Henrico County Regional Stormwater Management Plan

Henrico County's regional/watershed plan for stormwater management is a very good example of how a community can develop alternative approaches to comply with state stormwater management requirements. Several particular features exemplify the kinds of flexibility that may be achieved in such plans:

- The County designated its urban/commercial corridors as Intensely Developed Areas. New development or redevelopment occurring within these areas is not required to have on-site stormwater management practices, due to the high level of imperviousness and high cost of land typical of these sites. Instead, the developers are allowed to pay a fee-in-lieu of an amount calculated to cover the cost of treatment elsewhere that will achieve an equivalent amount of pollutant (phosphorus) reduction.
- The County uses funds collected from these fees to do one of two things: (1) build regional-scale stormwater management facilities (typically ponds); or (2) restore degraded stream corridors, using natural channel design techniques (a la David Rosgen) and creating new or expanded riparian forest buffers – often with level spreaders installed to ensure sheet flow through the buffers – adjacent to the County's stream system. This latter strategy aims at establishing a natural stream system that will convey storm flows without damage to the stream's structure or streambank erosion, which improves the eco-health of the streams. By reducing sediment loads from these streams, the County expects to also reduce a sufficient amount of attached phosphorus to achieve the equivalent levels of TP-reduction needed to comply with the state regulations.
- Developments everywhere in the County still must comply with water quantity requirements, to assure that flows discharged from development sites do not erode natural receiving channels or create nuisance flooding.
- Developments outside of the commercial corridor zones must, of course, provide traditional on-site stormwater management practices to achieve the water quality and water quantity requirements in the state regulations.

Of course, an important key to making a plan like Henrico's work well is the timing of the installation of the regional-scale SCMs and stream restoration/buffer projects. Simply allowing developers to pay into a fund that continually grows, without expending the funds in a timely manner to construct the offset measures, does not solve the stormwater problems. In fact, it allows more problems to occur during the waiting period. Prior to approving watershed plans, the DCR and the Board will expect localities to show how they will avoid this risk and assure timely implementation of offset measures.

Ideally, a community should identify sites for such regional facilities and prioritize stream restoration projects as part of the watershed plan. Then, through a bond mechanism or other up-

front funding, the community should construct offset measures fairly early in a watershed's development, using the collected fees-in-lieu to repay the bond or other debt obligations.

It is also possible for communities to establish Stormwater Utilities (§ 15.2-2114, Code of Virginia), charging local citizens service fees as they do for sewage and water treatment services, trash collection and recycling. The Stormwater Utility could be associated with the watershed plan, and some of the collected funds might be used to construct and maintain the offset SCMs.

5.4.2.2 Chesterfield County's Swift Creek Watershed Stormwater Management Plan

(Get information to describe this plan as a case study.)

5.4.3 Advantages of the Watershed Approach to Stormwater Management

The watershed approach has the following significant advantages over traditional piecemeal approaches to stormwater management that require individual land developments to provide on-site stormwater management facilities (adapted from Aldrich, 1988).

Lower capital and O&M Costs: Typically, watershed management plans yield fewer and larger stormwater management facilities. Economies of scale are achievable in capital costs and especially in Operation and Maintenance costs. Strategic placement of regional facilities permits concentrating funds on areas where potential benefits are greatest. Cost sharing arrangements significantly reduce the net cost of stormwater management to the community as a whole.

Increased effectiveness on a watershed-wide basis: Often different portions of watersheds require different types of stormwater controls. Watershed planning permits the siting of a variety of on-site and regional facilities in locations where the greatest benefits are achieved.

Greater use of nonstructural measures: Often the most practical stormwater controls involve nonstructural measures such as land acquisition, floodplain zoning, subdivision drainage ordinances, and land use controls. Watershed planning provides a coordinated comprehensive framework and decision-making process to allow the effective implementation of these measures.

Less risk of negative "spillover" effects: The piecemeal approach may adequately solve localized drainage problems, but seldom addresses downstream impacts. Thus, dynamic interactions between upstream drainage improvements may actually increase downstream flooding. An objective of watershed planning is to account for these upstream interactions and achieve solutions to both localized and regional stormwater management concerns.

Watershed management plans should include recommended criteria for stormwater source controls and treatment practices in the watershed. These criteria are based on watershed-specific factors such as physical attributes, land use, pollution sources, and sensitive receptors, and they are the basis for selecting and locating stormwater controls in the watershed. At a minimum, a watershed management plan should contain the elements listed in **Table 5.6** to address stormwater-related issues.

The watershed management plan should address integrating flood control and stormwater management controls with community needs, including open space, aesthetics, and other environmental objectives, such as habitat and stream restoration. This synchronization with other programs can create better funding opportunities and enhance the overall benefit of the stormwater management practices in the watershed.

Table 5.6. Elements of a Watershed Management Plan

Plan Elements	
Watershed delineation and identification of watershed characteristics such as topography, soils, surficial geology, impervious cover, and land use (current and projected)	A runoff hydrograph analysis of the watershed for floods of an appropriate duration, including a 24-hour event, with average return frequencies of 2, 10, 25, and 100 years for existing and future land uses
Inventory of flood hazard areas as identified by FEMA Flood Insurance Studies or DCR, plus historic floods and damages	The relationship between the computed peak flow rates and gauging station data, with modification or calibration of the hydrographs to obtain a reasonable fit where necessary
An evaluation of streams/watercourses, including areas of limited flow capacity, bank or bed erosion, sediment deposition, water quality, principle water uses and users, recreation areas, morphology classification, and channel stability	Identification of the peak rate of runoff at various key points in the watershed, and the relative timing of the peak flows
An inventory and evaluation of hydraulic structures, including culverts, bridges, dams and dikes, with information on their flow capacity and physical condition	Identification of points in the watershed where hydraulic structures or watercourses are inadequate under existing or anticipated future conditions
An inventory of significant water storage areas, including principal impoundments, floodplains, and wetlands	Recommendations on how the subwatershed's runoff can be managed to minimize any harmful downstream (flooding) impacts
Identification of sensitive and impaired wetlands and water bodies	Existing and projected future pollutant loads, impacts of these loads, and pollution reduction goals
Evaluation of functional value of wetlands to identify sensitive and high quality wetland resources	Existing and projected aquatic habitat disturbances and goals for habitat restoration
Sensitive groundwater recharge or aquifer protection areas	Recommendations for watershed-specific stormwater treatment controls, conceptual design, and operation and maintenance (O&M) needs and responsibilities
Identification of existing problem land uses and impacts on water quality	Water quality monitoring program
Land use restrictions in sensitive areas	Prioritized implementation plan for recommendations
Inventory of local wetlands, conservation, planning and zoning, and subdivision regulations of the watershed municipalities to identify potential regulatory changes for addressing stormwater impacts	Identification of public water supply watershed areas and identified aquifer recharge areas

5.4.4 On-Site Versus Regional Approaches

Watershed management plans can identify conditions and locations in the watershed where regional stormwater management facilities may be more appropriate or effective than on-site controls. On-site and regional stormwater management approaches are illustrated schematically in **Figure 5.5**. These approaches apply to both stormwater quality and quantity controls.

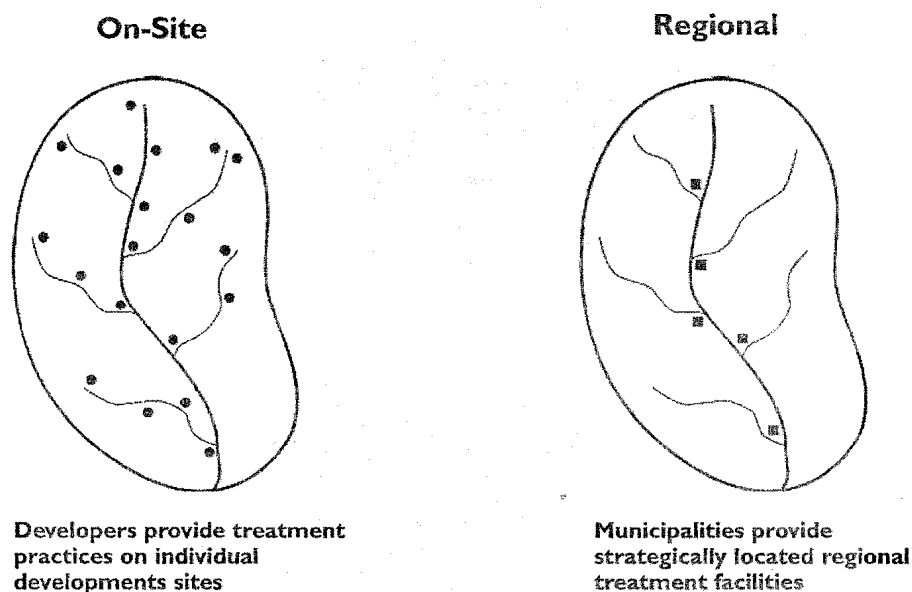


Figure 5.5. On-Site and Regional Stormwater Management Approaches

(Source: Adapted from Novotny, 1995, and Connecticut 2004 Stormwater Quality Manual)

In the on-site approach, land developers have responsibility for deploying treatment practices and runoff controls at individual development sites. Developers are responsible for constructing on-site stormwater management facilities to control stormwater pollutant loadings and the volume and flow rate of runoff from the site. The local government is responsible for reviewing the design of stormwater management facilities relative to specified design criteria, for inspecting the constructed facilities to ensure conformance with the design, and for ensuring that operation and maintenance plans are provided and implemented for the facilities (Novotny, 1995).

The watershed approach involves strategically siting stormwater management facilities to control stormwater runoff from multiple development projects or large drainage areas. Local or regional governments assume the capital costs for constructing the regional facilities. Capital costs are typically recovered from upstream developers as development occurs. Individual regional facilities are often sited and phased in as development occurs according to a comprehensive watershed management plan. Municipalities generally assume responsibility for operation and maintenance of regional stormwater facilities (Novotny, 1995).

Both approaches have a number of advantages and disadvantages, which are summarized in **Table 5.7**. Most of the advantages of the watershed approach can be attributed to the need for fewer stormwater management facilities that are strategically located throughout the watershed

(Novotny, 1995). However, the on-site approach addresses stormwater pollution close to its source, offers greater opportunities to preserve pre-development hydrologic conditions, and reduces the overall volume of stormwater runoff. Historically the on-site approach to stormwater management has been more common in Virginia. The major drawbacks that have limited the widespread use of the watershed approach include significant required advanced planning, financing, and land acquisition. Local governments must finance, design, and construct regional stormwater facilities before the majority of the watershed is developed, with reimbursement by developers over build-out periods of many years (WEF and ASCE, 1992). Due to these limitations, the watershed approach generally is more appropriate for (Pennsylvania Association of Conservation Districts et al., 1998):

- Highly developed watersheds with severe water quality and flooding impacts, where stormwater controls for new development alone cannot adequately address the impacts in these areas; and
- Watersheds where the timing of peak runoff may increase downstream flooding if on-site peak runoff attenuation criteria are applied uniformly throughout the watershed.

In most watersheds, a mix of regional and on-site controls is desirable and has the greatest potential for success when implemented as part of a comprehensive watershed management plan. (DEP, 1995).

5.4.5 Keys to Managing Stormwater on a Watershed Basis

The following are key elements of the watershed approach to stormwater management:

- Forecasting current and future development types
- Forecasting the scale of current and future development
- Choosing among on-site, distributed SCMs and larger, consolidated (regional) SCMs
- Defining stressors of concern
- Determining goals for the receiving water(s)
- Noting the physical constraints
- Developing SCM guidance and performance criteria specific to the local watershed
- Establishing a trading and offset system
- Ensuring the safe performance of the drainage network, streams, and floodplains
- Establishing community objectives for the publically owned elements of the stormwater infrastructure
- Establishing a long-term operation and maintenance plan for SCMs in the system

Table 5.7. Comparison of on-Site and Watershed Stormwater Management Approaches

Approach	Advantages	Disadvantages
On-site	<ul style="list-style-type: none"> Requires little or no advanced planning Addresses stormwater pollution close to its source—thereby reducing the volume of stormwater runoff and the need for treatment controls Provides greater groundwater recharge benefits 	<ul style="list-style-type: none"> Results in a large number of facilities that may not be adequately maintained by developers or homeowners Consumes on-site land that could be used for other purposes May increase downstream flooding and quantity control problems Encourage lower-density development and, thus, urban-suburban sprawl
Watershed	<ul style="list-style-type: none"> Reduced capital costs through economies of scale in designing and constructing regional facilities Reduced maintenance costs because there are fewer facilities to maintain Greater reliability because regional facilities are more likely to receive long-term maintenance Nonpoint source pollutant loadings from existing developed areas can be affordably controlled at the same regional facilities that are sited to control future development Regional facilities provide greater opportunities for multi-purpose uses that also provide recreational and aesthetic benefits, flood control, and wildlife habitat and corridors Can be used to treat runoff from public streets, which is often missed by on-site facilities Identifies opportunities to reduce regional stormwater pollutant loadings and provides a schedule for implementing appropriate controls 	<ul style="list-style-type: none"> Significant advanced watershed planning required Requires up-front financing Requires land availability and acquisition May promote “end-of-pipe” treatment mentality rather than the use of on-site controls to reduce stormwater runoff volume and the need for stormwater treatment Greater administrative responsibility for local governments Lack of sufficient design guidance for some non-traditional SCMs Lack of adequate training for local staff needed to administer such a program Some treatment practices are not appropriate for large drainage areas (e.g., swales, filter strips, media filters, and oil/particle separators, etc.) Potential for different standards applicable in neighboring jurisdictions within the same watershed Some safety or liability concerns for larger, regional facilities

5.4.6 Forecasting the Current and Future Development Types

Forecasting the type of current and future development within the local watershed will guide or shape how individual practices and SCMs are generally assembled at each individual site. The broad development categories that are generally thought of include (1) Greenfield development (small and large scales), which changes pristine or agricultural land to urban or suburban land uses, frequently low-density residential housing; (2) redevelopment within established communities and on Brownfield sites, which changes an existing urban land use to another, usually of higher density; and (3) retrofitting, which is not truly a development type, but rather an opportunity to upgrade stormwater management within an existing urban land use and drainage infrastructure to meet higher stormwater management standards. In Virginia, such a forecast will typically be associated with the community’s comprehensive land use plan.

Greenfield Development

Greenfield development requires new infrastructure designed according to contemporary design standards for roads, utilities, and related infrastructure. At the largest scale, Greenfield

development refers to planned communities at the developing edge of metropolitan areas, ranging from several hundred acres to tens of thousands of acres with long build-out schedules. They often include the trunk (primary) stormwater system as well as open stream and river corridors. The most progressive communities of this type incorporate a significant portion of the area to stormwater systems that exist as surface elements. Such stormwater system elements are typically at the subwatershed scale and provide for consolidated conveyance, detention, and water quality treatment. These elements of the infrastructure can be multi-functional in nature, providing for wildlife habitat, trail corridors, and open-space amenities.

Greenfield development can also occur on a small scale – neighborhoods or individual sites within newly developing areas that are served by the larger public and smaller site-by-site stormwater systems. This smaller scale, incremental expansion of existing urban patterns is a more typical way for cities to grow. A more limited range of SCMs and innovative stormwater management practices are available on smaller projects of this type, including what are referred to as LID practices.

Redevelopment

Redevelopment refers to developed areas undergoing land use change. In contrast to Greenfields, infrastructure in previously developed areas is often in poor condition, was not built to current design standards, and is inadequate for the new land uses proposed. Redevelopment within established communities is typically at the scale of individual sites and occasionally the scale of a small district. The area is usually served by private, on-site systems that convey larger storm events into pre-existing stormwater systems that were developed decades ago, either in historic city centers or in “first ring,” post-World War II suburbs adjacent to historic city centers. Redevelopment in these areas is typically much denser than the original use. The resulting increase in impervious area, and typically the inadequacy of existing stormwater infrastructure serving the site often results in significant development costs for on-site detention and water quality treatment. Elaborate vaults or related structures, or land area that could be utilized for development, must often be committed to on-site stormwater management to comply with current stormwater requirements.

Brownfields are redevelopments of industrial and often contaminated property at the scale of an individual site, neighborhood, or district. Secondary public systems and private stormwater systems on individual sites typically serve these areas. In many cases, especially in outdated industrial areas, little or no stormwater infrastructure exists, or it is so inadequate as to require replacement. Water quality treatment on contaminated sites may also be necessary. For these reasons, stormwater management in such developments presents special challenges. For example, the most common methods of remediation of contaminated sites involve capping of contaminated soils or treatment of contaminants in situ, especially where removal of contaminated soils from the site is cost-prohibitive. Given that contaminants are still often in place on redeveloped Brownfield sites and must not be disturbed, certain SCMs such as infiltration of stormwater into site soils, or excavation for stormwater piping and other utilities, present special challenges.

Each type of development has a different characteristic footprint, level of impervious cover, amount of open space, land cost, and existing stormwater infrastructure. Consequently, SCMs that

are ideally suited for one type of development may be impractical or infeasible for another. As might be expected, there are more options available for managing stormwater in Greenfield development than at redevelopment sites, and more options in redevelopment than for retrofitting existing urban areas.

Table 5.8 shows which broad SCM categories (from **Table 5.1**) are best suited for Greenfield development (particularly low-density residential), redevelopment of urban areas, and intense industrial redevelopment, which requires a substantially different suite of SCMs than for urban development.

Table 5.8. Applicability of Stormwater Control Categories by Type of Development

Stormwater Control Category	Low-Density Greenfield Development	Urban Redevelopment	Intense Industrial Redevelopment
1. Product Substitution	Sometimes	Often	Often
2. Watershed and Land-Use Planning	Always	Always	Sometimes
3. Conservation of Natural Areas	Always	Rarely	Sometimes
4. Impervious Cover Minimization	Always	Rarely	Rarely
5. Earthwork Minimization	Always	Rarely	Rarely
6. Erosion and Sediment Control	Always	Always	Always
7. Reforestation and Soil Conservation	Always	Often	Often
8. Pollution Prevention SCMs for Hotspots	Rarely	Often	Always
9. Runoff Volume Reduction – Rainwater Harvesting	Always	Always	Often
10. Runoff Volume Reduction – Vegetated	Always	Sometimes	Often
11. Runoff Volume Reduction – Subsurface	Always	Sometimes	Rarely
12. Peak Reduction and Runoff Treatment	Always	Rarely	Sometimes
13. Runoff Treatment	Sometimes	Sometimes	Always
14. Aquatic Buffers and Managed Floodplains	Often	Rarely	Sometimes
15. Stream Rehabilitation	Sometimes	Rarely	Rarely
16. Municipal Housekeeping	Sometimes	Sometimes	NA
17. Illicit Discharge Detection and Elimination	Sometimes	Sometimes	Sometimes
18. Stormwater Education	Often	Often	Often
19. Residential Stewardship	Always	Often	NA

5.4.7 Forecasting the Scale of Current and Future Development

The choice of what SCMs to use depends on the area that needs to be serviced. It turns out that some SCMs work best over a few acres, whereas others require several dozen acres or more. Some are highly effective only for the smallest sites, while other work best at the stream corridor or subwatershed level. **Table 5.1** includes a column (entitled “Where”) that is related to the scale at which individual SCMs can be applied. The SCMs mainly applied at the site scale include runoff volume reduction – rainwater harvesting, runoff treatment like filtering, and pollution prevention SCMs for hotspots. As one goes up in scale, SCMs like runoff volume reduction – vegetated and subsurface, earthwork minimization, and erosion and sediment control – take on a more prominent role. At the largest scales, watershed and land-use planning, conservation of natural areas, reforestation and soil conservation, peak flow reduction, buffers and managed floodplains, stream rehabilitation, municipal housekeeping, IDDE, stormwater education, and

residential stewardship play a more important role. Some SCMs are useful at all scales, such as product substitution and impervious cover minimization.

5.4.8 Choosing Among On-Site, Distributed SCMs and Larger, Consolidated SCMs

There are distinct advantages and disadvantages to consider when choosing to use a system of larger, consolidated SCMs versus smaller-scale, on-site SCMs that go beyond their ability to achieve water quality or urban stream health. Smaller, on-site facilities that serve to meet the requirements for residential, commercial and office developments tend to be privately owned. Typically, flows are directed to porous landscape detention areas or similar SCMs, such that volume and pollutants in stormwater are removed at or near their source. Quite often, these SCMs are relegated to the perimeter of projects, incorporated into detention ponds or, at best, developed as landscape infiltration and parking islands and buffers.

On-site infiltration of frequent storm events can also reduce the erosive impacts of stormwater volumes on downstream receiving waters. Maintenance is performed by the individual landowner, which is both an advantage (because the responsibility and costs for cleanup of pollutants generated by individual properties are equitably distributed) and a disadvantage (because ongoing maintenance incurs a significant expense on the part of the individual property owners and enforcement of properties not in compliance with required maintenance is difficult). On the negative side, individual SCMs often require additional land, which increases development costs and can encourage sprawl. Monitoring of thousands of SCMs in perpetuity in a typical city creates a significant ongoing public expense, and special training and staffing may be required to maintain SCM effectiveness (especially for subgrade or in-building vaults used in ultra-urban environments). Finally, given that as much as 30 percent of the urban landscape is comprised of public streets and rights-of-way, there are limited opportunities to treat runoff from streets through individual on-site private SCMs. (Notable exceptions are subsurface runoff volume reduction SCMs like permeable pavement that require no additional land and promote full development density within a given land parcel, because they use the soil areas below roads and the development site for infiltration.)

In contrast, publicly owned, consolidated SCMs are usually constructed as part of larger Greenfield and infill development projects in areas where there is little or no existing infrastructure. This type of facility – usually an infiltration basin, detention basin, wet/dry pond, or stormwater wetland – tends to be significantly larger, serving multiple individual properties. Such facilities are usually owned by the municipality, but they may be owned by a privately managed, quasi-public special district. There must be adequate land available to accommodate the facility and a means of up-front financing to construct the facility. An equitable means of allocating costs for ongoing maintenance must also be identified. However, the advantage of these facilities is that consolidation requires less overall land area, and treatment of public streets and rights-of-way can be addressed. Monitoring and maintenance are typically the responsibility of one organization, allowing for effective ongoing operations to maintain the original function of the facility. If that entity is public, this ensures that the facility will be maintained in perpetuity, allowing for the potential to permanently reduce stormwater volumes and for reduction in the size of downstream stormwater infrastructure. Because consolidated facilities are typically larger than on-site SCMs, mechanized maintenance equipment allows for greater efficiency and lower costs.

Finally, consolidated SCMs have great potential for multifunctional uses, because wildlife habitat, recreational, and open-space amenities can be integrated into their design.

5.4.9 Defining Stressors of Concern

The primary pollutants or stressors of concern (and the primary source areas or stormwater hotspots within the watershed likely to produce them) should be carefully defined for the watershed. Although the Virginia Stormwater Management Regulations dictate certain keystone pollutant removal criteria, it is important that the community ensure that SCMs are designed to prevent or reduce the maximum load of pollutants of greatest concern locally, as well, especially where TMDL waste load allocations are in place. The choice of pollutants of concern is very important, since individual SCMs have been shown to have highly variable capabilities to prevent or reduce specific pollutants.

5.4.10 Determining Goals for Receiving Waters

It is important to set biological and public health goals for the receiving water(s) that are achievable given the ultimate impervious cover intended for the local watershed. If the receiving water is too sensitive to meet these goals, one should consider adjustments to zoning and development codes to reduce the amount of impervious cover. The biological goals may involve a keystone species, such as trout or crabs, a desired state of biological integrity in a stream, or a maximum level of eutrophication in a lake. In other communities, stormwater goals may be driven primarily by the need to protect a sole-source drinking water supply or to maintain water contact recreation at a beach, lake or river. Once again, the watershed goals that are selected have a strong influence on the assembly of SCMs needed to meet them, since individual SCMs vary greatly in their ability to achieve different biological or public health outcomes. **Appendix 5-A** provides an explanation of the Impervious Cover Model, which is a useful management tool for diagnosing the severity of future stream problems in a subwatershed.

5.4.11 Noting the Physical Constraints

The specific physical constraints of the watershed terrain and the development pattern will influence the selection and assembly of SCMs. The application of SCMs must be customized in every watershed to reflect its unique terrain (such as karst, high water tables, low or high slopes, freeze-thaw depth, soil types, and underlying geology). Each SCM has different restrictions or constraints associated with these terrain factors. Consequently, the SCM prescription changes as one moves from one physiographic region to another (e.g., the flat coastal plain, the rolling Piedmont, the ridge and valley, and mountainous headwaters).

5.4.12 Developing SCM Guidance and Performance Criteria for the Local Watershed

Based on the foregoing factors and using state-established SCM specifications as a foundation, the community could consider adapting specific sizing, selection, and design requirements for SCMs, ensuring that the adaptations achieve equivalent water quality and quantity management results. The Virginia Stormwater Management Law allows localities to adopt criteria more *stringent* than

the State's criteria within certain parameters. The regulations also allow localities to disallow the use of some SCMs within their jurisdictions, subject to certain conditions. However, if adaptations are made, these need to be coordinated with the DCR and, ultimately, approved by the Virginia Soil and Water Conservation Board. Resulting SCM performance criteria may be established in a local or regional stormwater design manual or by reference in a local watershed management plan. In general, the watershed- or receiving water-based criteria are more specific and detailed than would be found in the State-established criteria. For example, the local stormwater guidance criteria may be more prescriptive with respect to runoff reduction and SCM sizing requirements, outline a preferred sequence for SCMs, and indicate where SCMs should (or should not) be located in the watershed. Like the identification of stressors or pollutants of concern, this step is rarely taken under current paradigms of stormwater management. The Minnesota Stormwater Steering Committee (MSSC, 2005) provides a good example of how SCM guidance can be customized to protect specific types of receiving waters (e.g., high quality lakes, trout streams, drinking water reservoirs, and impaired waters).

5.4.13 Establishing a Trading and Offset System

A stormwater trading or offset system is a critical option for situations when on-site SCMs are not feasible or desirable in the watershed. Communities may choose to establish some kind of stormwater trading or off-site mitigation system in the event that full compliance is not possible due to physical constraints or because it is more cost-effective or equitable to achieve pollutant reductions elsewhere in the local watershed. The most common example is providing an offset/in-lieu fee based on the cost to remove an equivalent amount of the target pollutant(s) (such as phosphorus here in Virginia). This kind of trading can provide for greater cost equity between low-cost Greenfield sites and higher-cost ultra-urban sites.

5.4.14 Ensuring the Safe and Effective Performance of the Drainage Network, Streams, and Floodplains

The urban water system is not solely designed to manage the quality of runoff. It also must be capable of safely handling flooding from extreme storms to protect life and property. Consequently, communities need to ensure that their stormwater infrastructure can prevent increased flooding caused by development (and possibly exacerbated future climate change). In addition, many SCMs must be designed to safely pass extreme storms when they do occur. This usually requires a watershed approach to stormwater management to ensure that quality and quantity control are integrated together, with an emphasis on the connection and effective use of conveyance channels, streams, riparian buffers, wetlands and floodplains.

In fact, in more undeveloped watersheds, consideration should be given to protecting the riparian corridors (streams, wetlands, and floodplains) from development encroachment and, where feasible, restoring degraded streams and wetlands. As Ian McHarg taught and practiced decades ago, this allows the natural system to function as nature intended – as the primary stormwater management system for the watershed. These corridors can be integrated into the community's public green space (parks, trails, recreation areas, etc).

5.4.15 Establishing Community Objectives for the Publicly Owned Elements of Stormwater Infrastructure

The stormwater infrastructure in a community normally occupies a considerable surface area of the landscape, once all the SCMs, drainage easements, buffers, and floodplains are added together. Consequently, communities may require that individual SCM elements are designed to achieve multiple objectives, such as landscaping, parks, recreation, greenways, trails, habitat, sustainability, and other community amenities (as discussed extensively above). In other cases, communities may want to ensure that SCMs do not cause safety or vector problems and that they look attractive. The best way to maximize community benefits is to provide clear guidance in local SCM criteria at the site level and to ensure that local watershed plans provide an overall context for their implementation.

5.4.16 Establishing an Inspection and Maintenance Plan

The long-term performance of any SCM is fundamentally linked to the frequency of inspections and maintenance. Lack of regular inspections and maintenance is truly the weak element of effective, on-going stormwater management. Without it, the considerable investment of time and money in SCMs is wasted after the fact. One can imagine the results if a person neglects to inspect and maintain the systems that sustain his or her home (water supply, sewage disposal, heating and air conditioning, landscaping, etc.) or automobile (tires, lubricants, coolant, brakes, engine parts, etc.). In short order, these very expensive investments would begin to break down and lose substantial value. The same is true of investments in our stormwater management systems, which serve individual homeowners, subdivisions and communities.

As a result of the historic lack of maintenance, Virginia's SWM regulations and permit conditions for industrial, construction, and municipal permittees specify that all SCMs must be adequately maintained. MS4 communities are also required under NPDES stormwater permits to track, inspect, and ensure the maintenance of the collective system of SCMs and stormwater infrastructure within their jurisdictions. In larger communities, this can involve hundreds or even thousands of individual SCMs located on either public or private property. In these situations, communities need to devise a workable model that will be used to operate, inspect, and maintain the stormwater infrastructure across their local watershed.

Communities have the lead responsibility in their MS4 permits to assure that SCMs are maintained properly to ensure their continued function and performance over time. They can elect to assign the responsibility to the public sector, the private sector (e.g., property owners and homeowners associations), or a hybrid of the two. But under their MS4 permits, they have ultimate responsibility to ensure that SCM maintenance actually occurs. This entails assigning legal and financial responsibilities to the owners of each SCM element in the watershed, as well as maintaining a tracking and enforcement system to ensure compliance. Maintenance should be a primary consideration in the watershed plan and provides an opportunity to achieve significant overall cost-efficiencies.

5.5 SUMMARY

Taking all of the elements above into consideration, **the emerging goal of stormwater management is to mimic, as much as possible, the hydrological and water quality processes of natural systems as rain travels from the roof to the stream, through combined application of a series of practices throughout the entire development site and extending to the stream corridor.** The series of SCMs incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required.

There is no single SCM prescription that can be applied to each kind of development; rather, a combination of interacting practices must be used for full and effective treatment. For a low-density residential Greenfield setting, a combination of SCMs that might be implemented is illustrated in **Table 5.9**. There are many successful examples of SCMs in this context and at different scales. By contrast, **Tables 5.10 and 5.11** outline how the general “roof-to-stream” stormwater approach is adapted for intense industrial operations and urban redevelopment sites, respectively. As can be seen, these development situations require a different combination of SCMs and practices to address the unique design challenges of dense urban environments. The tables are meant to be illustrative of certain situations; other scenarios, such as commercial development, would likely require additional tables.

In summary, a watershed approach for organizing site-based stormwater decisions is generally superior to making site-based decisions in isolation. Communities that adopt the preceding watershed elements not only can maximize the performance of the entire system of SCMs to meet local watershed objectives, but also can maximize other urban functions, reduce total costs, and reduce future maintenance burdens.

Table 5.9. From the Roof to the Stream: SCMs in a Residential Greenfield

SCM	What It Is	What It Replaces	How It Works
Land-Use Planning	Early Site assessment	Doing SWM design after site layout	Map and plan submitted at earliest stage of development review showing environmental, drainage, and soil features
Conservation of Natural Areas	Maximize forest canopy	Mass clearing	Preservation of priority forests and reforestation of turf areas to intercept rainfall
Earthwork Minimization	Conserve soils and contours	Mass grading and soil compaction	Construction practices to conserve soil structure and only disturb a small site footprint
Impervious Cover Minimization	Better (Environmental) Site Design	Large streets, lots and cul-de-sacs	Narrower streets, permeable driveways, clustering lots, and other actions to reduce site IC
Runoff Volume Reduction – Rainwater Harvesting	Utilize rooftop runoff	Direct connected roof leaders	A series of practices to capture, disconnect, store, infiltrate, or harvest rooftop runoff
Runoff Volume Reduction – Vegetated	Front yard bioretention	Positive drainage from rooftop to road	Grading front yard to treat roof, lawn, and driveway runoff using shallow bioretention
	Dry Swales	Curb/gutter and storm drain pipes	Shallow, well-drained bioretention swales located in the street right-of-way
Peak Reduction and Runoff Treatment	Linear Wetlands (Wet Swales)	Large detention ponds	Long, multi-cell, forested wetlands located in the stormwater conveyance system
Aquatic Buffers and Managed Floodplains	Stream buffer management	Unmanaged stream buffers	Active reforestation of buffers and restoration of degraded streams
NOTE: SCMs are applied in a series, although all of the above may not be needed at a given residential site. This “roof-stream” approach works best for low- to medium-density residential developments.			

Table 5.10. From the Roof to the Outfall: SCMs in an Industrial Context

SCM Category	What It Is	What It Replaces	How It Works
Pollution Prevention	Drainage mapping	No map	Analysis of the locations and connections of the stormwater and wastewater infrastructure from the site
	Hotspot site investigation	Visual inspection	Systematic assessment of runoff problems and pollution prevention opportunities at the site
	Rooftop management	Uncontrolled rooftop runoff	Use of alternative roof surfaces or coatings to reduce metal runoff, and disconnection of roof runoff for stormwater treatment
	Exterior maintenance practices	Routine plant maintenance	Special practices to reduce discharges during painting, power washing, cleaning, seal coating and sandblasting
	Extending roofs for no exposure	Exposed hotspot operations	Extending covers over susceptible loading/unloading, fueling, outdoor storage, and waste management operations
	Vehicular pollution prevention	Uncontrolled vehicle operations	Pollution prevention practices applied to vehicle repair, washing, fueling, and parking operations
	Outdoor pollution prevention practices	Outdoor materials storage	Prevent rainwater from contact with potential pollutants by covering, secondary containment, or diversion from the storm-drain system
	Waste management practices	Exposed dumpster or waste streams	Improved dumpster location, management, and treatment to prevent contact with rainwater or runoff
	Spill control plan and response	No plan	Develop and text response to spills to the storm drain system, train employees, and have spill control kits available on-site
	Greenscaping	Routine landscape and turf maintenance	Reduce use of pesticides, fertilization, and irrigation in pervious areas, and convert turf to forest cover
	Employee stewardship	Lack of stormwater awareness	Regular ongoing training of employees on stormwater problems and pollution prevention practices
	Site housekeeping and stormwater maintenance	Dirty site and unmaintained infrastructure	Regular sweeping, storm-drain cleanouts, litter pickup, and maintenance of stormwater infrastructure
Runoff Treatment	Stormwater retrofitting	No stormwater treatment	Filtering retrofits to remove pollutants from the most severe hotspot areas
IDDE	Outfall analysis	No monitoring	Monitoring of outfall quality to measure effectiveness
NOTE: While many SCMs are used at each individual industrial site, the exact combination depends on the specific configuration, operations, and footprint of each site.			

Table 5.11. From the Roof to the Street: SCMs in a Redevelopment Context

SCM Category	What It Is	What It Replaces	How It Works
Impervious Cover Minimization	Site design to prevent pollution	Conventional site design	Designing the redevelopment footprint to restore natural area remnants, minimize needless impervious cover, and reduce hotspot potential
Runoff Volume Reduction – Rainwater Harvesting and Vegetated Roofs	Treatment on the roof	Traditional rooftops	Use of green rooftops to reduce runoff generated from roof surfaces
	Rooftop runoff treatment	Directly connected roof leaders	Use of rain tanks, cisterns, and rooftop disconnection to capture, store, and treat runoff
	Runoff treatment in landscaping	Traditional landscaping	Use of foundation planters and bioretention areas to treat runoff from parking lots and rooftops
Soil Conservation and Restoration	Runoff reduction in pervious areas	Impervious areas or compacted soils	Reducing runoff from compacted soils through tilling and compost amendments, and in some cases, removal of unneeded impervious cover
	Increase urban tree canopy	Turf or landscaping	Providing adequate rooting volume to develop mature tree canopy to intercept rainfall
Runoff Reduction – Subsurface	Increase permeability of impervious cover	Hard asphalt or concrete	Use of permeable pavers, porous concrete, and similar products to decrease runoff generation from parking lots and other hard surfaces
Runoff Reduction – Vegetated	Runoff treatment in the street	Sidewalks, curb and gutter, and storm drains	Use of expanded tree pits, dry swales and street bioretention cells to further treat runoff in the street or its right-of-way
Runoff Treatment	Underground treatment	Catch basins and storm-drain pipes	Use of underground sand filters and other practices to treat hotspot runoff quality at the site
Municipal Housekeeping	Street Cleaning	Unswept streets	Targeted street cleaning on priority streets to remove trash and gross solids
Watershed Planning	Off-site stormwater treatment or mitigation	On-site waivers	Stormwater retrofits or restoration projects elsewhere in the watershed to compensate for stormwater requirements that cannot be met on-site
NOTE: SCMs are applied in series, although all of the above may not be needed at a given redevelopment site.			

5.6 INTEGRATING WATERSHED PLANS INTO ENFORCEABLE PERMITS

As noted earlier, most of the planning, engineering, and regulatory responses to the ICM are not effective unless they are applied together in the context of a local watershed plan. The mere existence of a plan is not result in effective stormwater management unless it is fully implemented. Relatively few watershed protection or restoration plans have progressed into actual implementation, primarily because there is no mechanism for accountability and enforcement. The clear implication is that local subwatershed plans must be translated into a long term

watershed-based permit to ensure implementation. The best permitting vehicle appears to be the municipal NPDES stormwater permit system. With some adaptation, these permits can be implemented on a subwatershed basis, using the process outlined below:

Step 1. Define interim water quality and stormwater goals (i.e., pollutants of concern, biodiversity targets) and the primary pollutant source areas and hotspots that cause them.

Step 2. Delineate subwatersheds within community boundaries.

Step 3. Measure current and future impervious cover within individual subwatersheds.

Step 4. Establish the initial subwatershed management classification using ICM.

Step 5. Undertake field monitoring to confirm or modify individual subwatershed classifications)

Step 6. Develop customized management strategies within each subwatershed classification that will guide or shape how land use decisions are made at the subwatershed level, and how watershed practices will generally be assembled at individual sites

Step 7. Undertake restoration investigations to verify restoration potential in priority subwatersheds

Step 8. Agree on the specific implementation measures that will be completed within the permit cycle. Evaluate the extent to which each of the six minimum management practices can be applied in each subwatershed to meet municipal objectives

Step 9. Agree on the maintenance model that will be used to operate or maintain the stormwater infrastructure, assign legal and financial responsibilities to the owners of each element of the system, and develop a tracking and enforcement system to ensure compliance.

Step 10. Define the trading or offset system that will be used to achieve objectives elsewhere in the local watershed objectives in the event that full compliance cannot be achieved due to physical constraints.

Step 11. Establish sentinel monitoring stations in select subwatersheds to measure progress towards goals.

Step 12. Revise subwatershed management plans in the subsequent NPDES permitting cycle, based on monitoring data.

The core of the approach is to customize management strategies for each class of subwatershed so as to apply the most appropriate planning, engineering and regulatory tool (see **Table 5.12**). The benefit of subwatershed-based permits is that it also provides accountability mechanism in the form of compliance monitoring on a subwatershed basis. In all subwatersheds, it makes sense to measure and track changes in both IC created and IC treated. Within individual subwatersheds,

however, the focus of monitoring efforts may differ. For example, monitoring of biological metrics is recommended in sensitive and impacted streams to ensure they are meeting their objectives. Outfall monitoring continues to be important for non-supporting streams (i.e., no biological diversity), particularly if stormwater quality data are compared to action levels to identify the most polluted subwatersheds for greater treatment.

Table 5.12: Examples of Customized Subwatershed Management Strategies

Subwatershed Management Issue	Sensitive Streams (2 to 10% IC)	Impacted (IC 10 to 24%)	Non-Supporting (IC 25 to 59%)	Urban Drainage (60% + IC)
Land Use Planning and Zoning	Extensive land conservation and acquisition to preserve natural land cover. Site-based or watershed IC caps	Reduce IC created for each zoning category by changing local codes and ordinances	Encourage redevelopment, and intensification of development to decrease per-capita IC utilization in the landscape. Develop watershed restoration plans to maintain or enhance aquatic resources	
Site-Based Stormwater Reduction and Treatment Objectives	Treat runoff from two year design storm using practices to achieve 100% runoff reduction volume	Treat runoff from one year design storm using practices to achieve 75% runoff reduction volume	Treat runoff from the 90% annual storm and achieve at least 50% runoff reduction volume	Treat runoff from the first flush storm and achieve at least 25% runoff reduction volume
Site-Based IC Fees	Establish Excess IC Fee for projects that exceed IC zoning category		Allow IC Mitigation Fee	Allow IC Mitigation Fee
Subwatershed Trading	Receiving Area for Conservation Easements, Restoration Projects and Retrofit		Receiving or Sending Area for Retrofit	Sending Area, for Restoration Projects
Stormwater Monitoring Approach	Measure in-stream metrics of biotic integrity	Track subwatershed IC and measure practice performance	Check outfalls and measure practice performance	Check municipal action levels at outfalls
TMDL Approach	Protect using anti-degradation provisions	IC-based TMDLs that use flow or IC as a surrogate for traditional pollutants	Pollutant TMDLs to identify problem subwatersheds	Pollutant TMDLs to identify priority source areas
Dry Weather Water Quality	Check for failing septic system	Outfall and channel screening for illicit discharges	Dry weather sampling in streams and outfall screening	Dry weather sampling in receiving waters
Addressing Existing Development	Ensure farm, pasture and forest best practices are used	Stream repairs, riparian reforestation & residential stewardship	Storage retrofits and stream repairs	Pollution source controls and municipal housekeeping

Managing urban watersheds can be challenging. The best chance of achieving stream quality objectives arises when the many tools of watershed protection and restoration are organized and

aligned in the context of an ICM-based stream classification system and an enforceable watershed-based permit system is established to implement them. The proposed approaches outlined in this chapter are intended to be an initial guide to help local managers to shift to a new subwatershed approach.

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Practice No. 77).

Appendix 5-A

The Impervious Cover Model: An Emerging Framework for Urban Stormwater Management

5-A.1 INTRODUCTION

Impervious cover (IC) has unique properties as a watershed metric in that it can be measured, tracked, forecasted, managed, priced, regulated, mitigated and, in some cases, even traded. In addition, IC is a common currency that is understood and applied by watershed planners, stormwater engineers, water quality regulators, economists and stream ecologists alike. IC can be accurately measured using either remote sensing or aerial photography (Goetz et al. 2003 and Jantz et al. 2005). IC is also strongly correlated with individual land use and zoning categories (Cappiella and Brown 2001; Slonecker and Tilley 2004) which allows planners to reliably forecast how it changes over time in response to future development. Consequently, watershed planners rely on IC (and other metrics) to predict changes in stream health as a consequence of future development (CWP 1998).

Schueler (2004) has utilized IC to classify and manage urban streams, and economists routinely use IC to set rates for stormwater utilities and off-site mitigation (Parikh et al. 2005). Regulators and engineers utilize IC as a key input variable to predict future downstream hydrology and design stormwater management practices (MPCA 2005). A number of localities have modified their zoning to establish site-based or watershed-based IC caps to protect streams or drinking water supplies. In recent years, IC has been used as a surrogate measure to ensure compliance with water quality standards in impaired urban waters (Bellucci 2007).

Another noteworthy aspect of IC has been its use as an index of the rapid growth in land development or sprawl at the watershed, regional and national scale. For example, Jantz et al. (2005) found that IC increased at a rate five times faster than population growth between 1990 and 2000 in the Chesapeake Bay watershed – over 76,000 acres of impervious cover and over 232,000 acres of turf cover are created each year, or nearly 1 percent of the watershed per year. At a national level, several recent estimates of IC creation underscore the dramatic changes in many of our nation's watersheds as a result of recent or future growth. Elvidge et al. (2004) estimated that about 112,665 km² (43,500 mi²) of IC had been created in the lower 48 states as of 2000. Forecasts by Beach (2002) indicate that IC may nearly double by the year 2025 to about 213,837 km² (82,563 mi²), given current development trends. Although care must be taken when extrapolating from national estimates, it is clear that several hundred thousand stream miles are potentially at risk. For example, a detailed GIS analysis by Exum et al. (2006) indicates that 14% of the total watershed area in eight Southeastern states had exceeded 5% IC as of 2000.

Given growth in IC, watershed managers are keenly interested in the relationship between subwatershed IC and various indicators of stream quality. The Impervious Cover Model (ICM) was first proposed by Schueler (1994) as a management tool to diagnose the severity of future stream problems in urban subwatersheds. The ICM projects that hydrological, habitat, water quality and biotic indicators of stream health decline at around 10% total IC in small

subwatersheds (i.e., 5 to 50 km²) (CWP 2003). The ICM defines four categories of urban streams based on how much impervious cover exists in their subwatershed:

- Sensitive (high-quality) streams
- Impacted streams
- Non-supporting streams, and
- Urban drainage.

The ICM is then used to develop specific quantitative or narrative predictions for stream indicators within each stream category (see **Figure 5-A.1**). These predictions define the severity of current stream impacts and the prospects for their future restoration. Predictions are made for five kinds of urban stream impacts: changes in stream hydrology, alteration of the stream corridor, stream habitat degradation, declining water quality, and loss of aquatic diversity. The model is intended to predict the average behavior of this group of indicator responses over a range of IC, rather than predicting the precise score of an individual indicator.

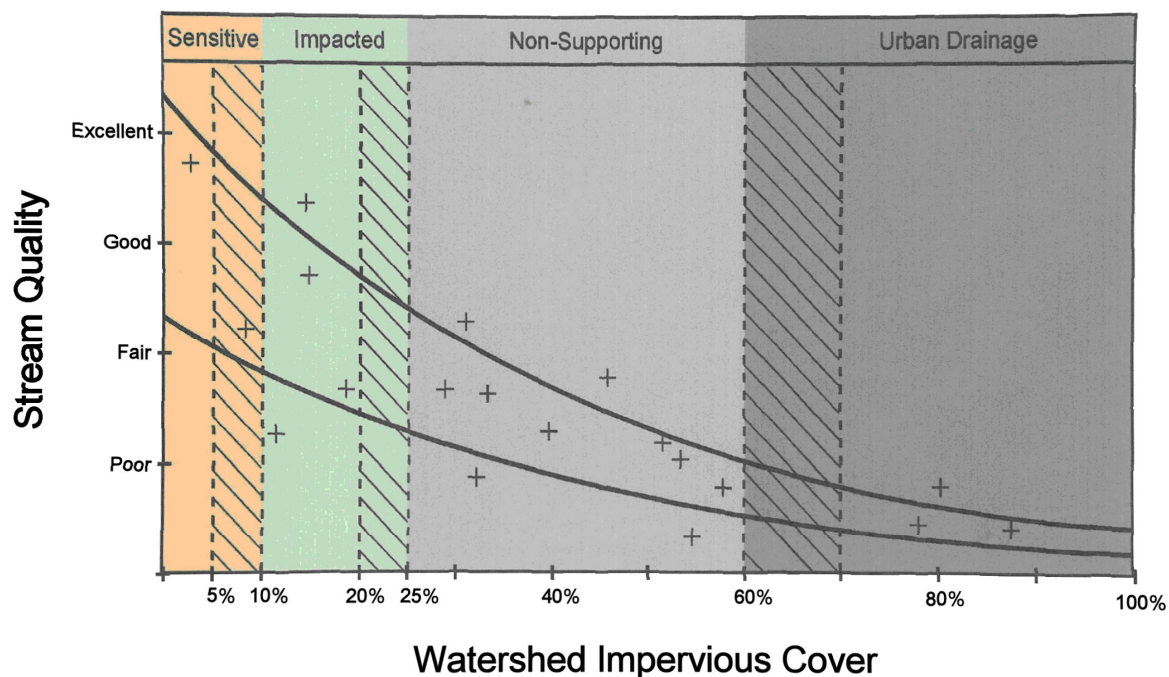


Figure 5-A.1. Reformulated Impervious Cover Model Reflecting Changes in Stream Quality in Response to Percent Impervious Cover in the Contributing Watershed.

(Source: Chesapeake Stormwater Network, 2008)

5-A.2 THE REFORMULATED IMPERVIOUS COVER MODEL

The reformulated ICM includes three important changes to the original conceptual model proposed by Schueler (1994). First, the IC/stream quality relationship is no longer expressed as a straight line, but rather as a “cone” that is widest at lower levels of IC and progressively narrows at higher IC. The cone represents the observed variability in the response of stream indicators to urban disturbance and also the typical range in expected improvement that could be attributed to

subwatershed treatment. In addition, the use of a cone rather than a line is consistent with the findings that exact, sharply defined IC thresholds are rare, and that most regions show a generally continuous but variable gradient of stream degradation as IC increases.

Second, the cone width is greatest for IC values less than 10%, which reflects the wide variability in stream indicator scores observed for this range of streams. This modification prevents the misperception that streams with low subwatershed IC will automatically possess good or excellent quality. As noted earlier, the expected quality of streams in this range of IC is generally influenced more by other watershed metrics such as forest cover, road density, riparian continuity, and cropping practices. This modification suggests that IC should not be the sole metric used to predict stream quality when subwatershed IC is very low.

Third, the reformulated ICM now expresses the transition between stream quality classifications as a band rather than a fixed line (e.g., 5 to 10% IC for the transition from sensitive to impacted, 20 to 25% IC for the transition from impacted to non-supporting, and 60 to 70% IC for the transition from non-supporting to urban drainage). The band reflects the variability in the relationship between stream hydrologic, physical, chemical, and biological responses and the qualitative endpoints that determine stream quality classifications. It also suggests a watershed manager's choice for a specific threshold value to discriminate among stream categories should be based on actual monitoring data for their ecoregion, the stream indicators of greatest concern and the predominant predevelopment regional land cover (e.g., crops or forest).

5-A.3 GENERAL PREDICTIONS OF THE IMPERVIOUS COVER MODEL

The ICM is similar to other models that describe ecological response to stressors from urbanization in that the stream quality classifications are value judgments relative to some endpoint defined by society (e.g., water quality criteria). The ICM differs from most other models in that it provides a broader focus on a group of stream responses, yet focuses on only one stressor, impervious cover. The focus on IC allows watershed managers to use the ICM both to predict stream response and to manage future impacts by measuring and managing IC.

The general predictions of the ICM are as follows:

- Stream segments with less than 10 percent impervious cover (IC) in their contributing drainage area continue to function as Sensitive Streams, and are generally able to retain their hydrologic function and support good-to-excellent aquatic diversity.
- Stream segments that have 10-25 percent IC in their contributing drainage area behave as Impacted Streams and show clear signs of declining stream health. Most indications of stream health will fall in the fair range, although some segments may range from fair to good, as riparian cover improves. The decline in stream quality is greatest toward the higher end of the IC range.
- Stream segments with subwatershed IC that ranges from 25-60 percent are classified as non-supporting streams (i.e., no biological diversity). These stream segments become so degraded that any future stream restoration or riparian cover improvements are insufficient to fully

recover stream function and diversity (i.e., the streams are so dominated by subwatershed IC that they cannot attain pre-development conditions).

- Stream segments whose subwatersheds exceed 60 percent IC are physically altered so that they merely function as a conduit for flood waters. These streams are classified as Urban Drainage and consistently have poor water quality, highly unstable channels, and very poor habitat and biodiversity scores. In many cases these urban stream segments are eliminated altogether by earthworks and/or storm drain enclosures. **Table 5-A.1** shows in greater detail how stream corridor indicators respond to greater subwatershed impervious cover.

Table 5-A.1. General ICM Predictions Based on Urban Subwatershed Classification

Prediction	Impacted (IC = 11-25%) ⁸	Non-Supporting (IC = 26-60%)	Urban Drainage (IC = ≥ 60%)
Runoff as a fraction of annual rainfall ¹	10 to 20%	25 to 60%	60 to 90%
Frequency of bankfull flow per year ²	1.5 to 3 per year	3 to 7 per year	7 to 10 per year
Fraction of original stream network remaining	60 to 90%	25 to 60%	10 to 30%
Fraction of riparian forest buffer intact	50 to 70%	30 to 60%	Less than 30%
Crossings (roads/utilities, etc.) per stream mile	1 to 2	2 to 10	None left
Ultimate channel enlargement ratio ³	1.5 to 2.5 times larger	2.5 to 6 times larger	6 to 12 times larger
Typical stream habitat score	Fair, but variable	Consistently poor	Poor, often absent
Increased stream warming ⁴	2 to 4 °F	4 to 8 °F	8+ °F
Annual nutrient load ⁵	1 to 2 times higher	2 to 4 times higher	4 to 6 times higher
Wet weather violations of bacteria standards	Frequent	Continuous	Ubiquitous
Fish advisories	Rare	Potential risk of accumulation	Should be presumed
Aquatic insect diversity ⁶	Fair to good	Fair	Very poor
Fish diversity ⁷	Fair to good	Poor	Very poor

¹ Based on annual storm runoff coefficient ranges from 2 to 5% for undeveloped systems.
² Predevelopment bankfull flood frequency is about 0.5 per year, or about one bankfull flood every two years.
³ Ultimate stream channel cross-section compared to typical predevelopment channel cross section.
⁴ Typical increase in mean summer stream temperature in degrees Fahrenheit compared with shaded rural stream.
⁵ Annual unit area stormwater phosphorus and/or nitrogen load produced from a rural subwatershed.
⁶ As measured by benthic index of biotic integrity. Scores for rural streams range from good to very good.
⁷ As measured by fish index of biotic integrity. Scores for rural streams range from good to very good.
⁸ IC is not the strongest indication of stream health below 10% IC, so the sensitive streams category is omitted from this table

Source: CWP, 2004

5-A.4 SCIENTIFIC SUPPORT FOR THE ICM

The ICM predicts that hydrological, habitat, water quality, and biotic indicators of stream health first begin to decline sharply at around 10 percent total IC in smaller catchments (Schueler, 1994). The ICM has since been extensively tested in ecoregions around the United States and elsewhere, with more than 200 different studies confirming the basic model for single stream indicators or groups of stream indicators (CWP, 2003; Schueler, 2004). Several recent research studies have reinforced the ICM as it is applied to 1st-to-3rd order streams (Coles et al., 2004; Horner et al., 2004; Deacon et al., 2005; Fitzpatrick et al., 2005; King et al., 2005; McBride and Booth, 2005; Cianfrina et al., 2006; Urban et al., 2006; Schueler et al., 2008).

Researchers have focused their efforts to define the specific thresholds where urban stream degradation first begins. There is robust debate as to whether there is a sharp initial threshold or

merely a continuum of degradation as IC increases, although the latter view is more favored. There is much less debate, however, about the dominant role of IC in defining the hydrologic, habitat, water quality, and biodiversity expectations for streams with higher levels of IC (15 to 60 percent).

5-A.5 CAVEATS TO THE ICM

The ICM is a powerful predictor of urban stream quality when used appropriately. The first caveat is that subwatershed IC is defined as total impervious area (TIA, which includes *all* impervious cover) and *not* the effective impervious area (EIA, which is the portion of the TIA that is directly connected to the drainage collection system). Second, application of the ICM should be restricted to 1st-to-3rd order alluvial streams with moderate gradient and no major point sources of pollutant discharge. The ICM is most useful in projecting the behavior of numerous stream health indicators, and it is not intended to be accurate for every individual stream indicator. In addition, management practices in the contributing catchment or subwatershed must *not* be poor (e.g., no deforestation, acid mine drainage, intensive row crops, etc.); just because a subwatershed has less than 10 percent IC does not automatically mean that it will have good or excellent stream quality, if past catchment management practices were poor.

ICM predictions are general and may not apply to every stream within the proposed classifications. Urban streams are notoriously variable, and factors such as gradient, stream order, stream type, age of subwatershed development, and past land use can and will make some streams depart from these predictions. Indeed, these atypical streams are extremely interesting from the standpoint of restoration. In general, subwatershed IC causes a continuous but variable decline in most stream corridor indicators. Consequently, the severity of individual indicator impacts tends to be greater at the upper end of the IC range for each stream category.

5-A.6 EFFECTS OF CATCHMENT TREATMENT ON THE ICM

Most studies that investigated the ICM were done in communities with some degree of catchment treatment (e.g., stormwater management or stream buffers). Detecting the effect of catchment treatment on the ICM involves a very complex and difficult paired watershed design. Very few catchments meet the criteria for either full treatment or the lack of it; no two catchments are ever really identical, and individual catchments exhibit great variability from year to year. Not surprisingly, the first generation of research studies has produced ambiguous results. For example, seven research studies showed that ponds and wetlands are unable to prevent the degradation of aquatic life in downstream channels associated with higher levels of IC (Galli, 1990; Jones et al., 1996; Horner and May, 1999; Maxted, 1999; MNCPPC, 2000; Horner et al., 2001; Stribling et al., 2001). The primary reasons cited are stream warming (amplified by the presence of ponds), changes in organic matter processing, the increased runoff volumes delivered to downstream channels, and habitat degradation caused by channel enlargement.

Riparian forest cover is defined as canopy cover within 100 meters of the stream, and is measured as the percentage of the upstream network in this condition. Numerous researchers have evaluated the relative impact of riparian forest cover and IC on stream geomorphology, aquatic insects, fish assemblages, and various indices of biotic integrity. As a group, the studies suggest that indicator

values for urban streams improve when riparian forest cover is retained over at least 50 to 75 percent of the length of the upstream network (Booth et al., 2002; Morley and Karr, 2002; Wang et al., 2003; Allan, 2004; Sweeney et al., 2004; Moore and Palmer, 2005; Cianfrina et al., 2006; Urban et al., 2006). The studies also indicate that downstream improvements in some stream quality indicators may still be observed when an unforested stream segment flows into a long segment of extensive riparian forest or wetland cover.

5-A.7 APPLICATION OF THE ICM TO OTHER RECEIVING WATERS

Recent research has focused on the potential value of the ICM in predicting the future quality of receiving waters such as tidal coves, lakes, wetlands and small estuaries. The primary work on small estuaries by Holland et al. (2004) [references cited in CWP (2003), Lerberg et al. (2000)] indicates that adverse changes in physical, sediment, and water quality variables can be detected at 10 to 20 percent subwatershed IC, with a clear biological response observed in the range of 20 to 30 percent IC. The primary physical changes involve greater salinity fluctuations, greater sedimentation, and greater pollutant contamination of sediments. The biological response includes declines in diversity of benthic macroinvertebrates, shrimp, and finfish.

More recent work by King et al. (2005) reported a biological response for coastal plain streams at around 21 to 32 percent urban development (which is usually about twice as high as IC). The thresholds for important water quality indicators, such as bacterial counts that exceed regulatory limits in shellfish beds and beaches, appears to begin at about 10 percent subwatershed IC, with chronic violations observed at 20 percent IC (Mallin et al., 2001). Algal blooms and anoxia resulting from nutrient enrichment by stormwater runoff also are routinely noted at 10 to 20 percent subwatershed IC (Mallin et al., 2004).

The primary conclusion to be drawn from the existing science is that the ICM does apply to tidal coves and streams, but the impervious levels associated with particular biological responses appear to be higher (20 to 30 percent IC for significant declines) than for freshwater streams, presumably due to their greater tidal mixing and inputs from near-shore ecosystems. The ICM may also apply to lakes (CWP, 2003) and freshwater wetlands (Wright et al., 2007) under carefully defined conditions. The initial conclusion is that the application of the ICM shows promise under special conditions, but more controlled research is needed to determine if IC (or other watershed metrics) is useful in forecasting receiving water quality conditions.

5-A.8 UTILITY OF THE ICM IN URBAN STREAM CLASSIFICATION AND WATERSHED MANAGEMENT

The ICM is best used as an urban stream classification tool to set reasonable expectations for the range of likely stream quality indicators (e.g., physical, hydrologic, water quality, habitat, and biological diversity) over broad ranges of subwatershed IC. In particular, it helps define general thresholds where water quality standards or biological narrative conditions cannot be consistently met during wet weather conditions (**Table 5-A.2**). These predictions help stormwater managers and regulators to devise appropriate and geographically explicit stormwater management and subwatershed restoration strategies for their catchments as part of MS4 permit compliance. More specifically, assuming that local monitoring data are available to confirm the general predictions

of the ICM, it enables managers to manage stormwater within the context of current and future watershed conditions.

Table 5-A.2. Expectations for Different Urban Subwatershed Classes

Condition	Expectation
Sensitive Streams (2 to 10% IC) ¹	<ul style="list-style-type: none"> Maintain or restore ecological structure, function and diversity so streams provide a “rural” benchmark with which to compare other stream categories Specific stream quality indicators for sensitive streams should be compared to streams whose entire subwatersheds are fully protected (e.g., national parks, etc.)
Impacted Subwatersheds (11 to 25% IC)	<ul style="list-style-type: none"> Consistently attain “good” stream quality indicator scores to ensure enough stream function to adequately protect downstream receiving waters from degradation. Function is defined in terms of flood storage, in-stream nutrient processing, biological corridors, stable stream channels, and other factors.
Non-Supporting Subwatersheds (26 to 59% IC)	<ul style="list-style-type: none"> Consistently attain “fair to good” stream quality indicator scores. Meet bacteria standards during dry weather and trash limits during wet weather. Maintain existing stream corridor to allow for safe passage of fish and floodwaters.
Urban Drainage Subwatersheds (60 to 100% IC)	<ul style="list-style-type: none"> Maintain “good” water quality conditions in downstream receiving waters. Consistently attain “fair” water quality scores during wet weather and “good” water quality scores during dry weather. Provide clean “plumbing” in upland land uses such that discharges of sewage and toxics do not occur.
¹ The specific ranges in IC that define each management category should always be derived from local or regional monitoring data.	

5-A.9 REVIEW OF MANAGEMENT RESPONSES TO THE ICM

The diversity in management responses to the ICM is fairly impressive. **Table 5-A.3** classifies the nearly 20 different planning, engineering, regulatory and economic tools that have been used (or proposed) to respond to the ICM. In general, each of these individual professional disciplines has adopted their own tools and methods to mitigate the effect of land development on water quality, and has rarely coordinated with other disciplines. This section reviews the strengths and weaknesses of the many different approaches to managing IC at the watershed and community scale.

5-A.9.1 Planning and Zoning Responses to the ICM

Planning responses are handicapped by the fact that that nearly all rural and suburban zoning categories produce more than 10% IC. This can be seen in **Figure 5-A.2**, which portrays data from Cappiella and Brown (2001) on the IC produced by different rural and suburban zones in four Chesapeake Bay communities. Only agricultural preservation zones and open urban land (e.g., parks, cemeteries and golf courses) produced less than 10% IC. This suggests that even low levels of new land development in a subwatershed will degrade streams and receiving waters to some degree.

Table 5-A.3. Range of Management Responses to the ICM

Planning and Zoning Tools	Engineering Tools
<ul style="list-style-type: none"> Better (Environmental) Site Design Large-Lot Zoning Site-Based IC Caps Watershed-Based IC Caps Development Intensification Watershed-Based Zoning Watershed Planning 	<ul style="list-style-type: none"> Traditional Stormwater Treatment Requirements Runoff Volume Reduction Practices Special Subwatershed Stormwater Criteria Watershed Restoration Plans
Regulatory Tools	Economic Tools
<ul style="list-style-type: none"> Anti-Degradation Provisions IC-Based TMDLs Watershed-Based Permitting 	<ul style="list-style-type: none"> IC-Based Stormwater Utilities Excess IC Fees IC Mitigation Fees Subwatershed IC Trading

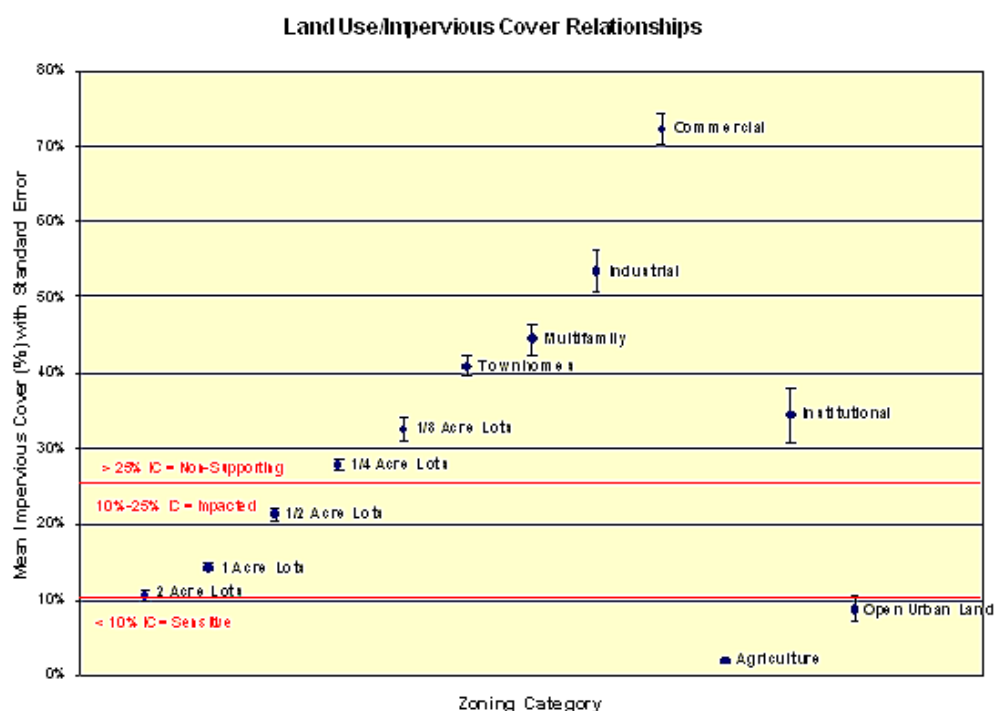


Figure 5-A.2. Relationship between impervious cover and zoning category
 (Adapted from Cappiella and Brown, 2001)

[NOTE: Need to sharpen the text in this Figure.]

This creates a difficult choice for land planners. On one hand, low density development reduces the extent of stream damage but spreads it out over a wider geographic area and thereby accentuates sprawl. More intense development, on the other hand, greatly increases local stream degradation to the point that many urban communities cannot meet water quality standards and may be subject to an uncertain future restoration liability. Communities have responded to this dilemma by pursuing several planning and zoning responses, as described below.

Better (Environmental) Site Design. This strategy relies on the fact that nearly 65% of new impervious cover can be classified as car habitat (Cappiella and Brown 2001) and focuses on changing local development codes to minimize the geometry of roads, parking lots, sidewalks, cul-de-sacs and other new development infrastructure. These techniques, which are collectively referred to as Better Site Design (BSD) or Environmental Site Design (ESD), can also include greater use of swales, relaxed lot geometry, natural area conservation, open-space subdivisions, pervious paving and other site design techniques (CWP 1998a). Several dozen communities across the country have changed their local codes and ordinances to promote BSD through a roundtable process to gain consensus among development stakeholders. The strength of the BSD approach is that numerous modeling studies have demonstrated it can reduce IC, pollutants and development costs by as much as 10 to 40% at individual development sites (Kloss and Calarusse 2006; CWP 1998b). The weakness of BSD is that it lacks a watershed context and therefore reductions in site IC may not be enough to meet subwatershed objectives.

Extremely Large Lot Zoning. Several communities have adopted extremely large lot zoning to protect sensitive streams in designated planning areas. Often, these zones are accompanied by decisions to restrict or exclude public water and sewer service. This form of very low-density residential development often involves densities ranging from 0.5 to 0.05 dwelling units per acre, and may also involve conservation easements to protect existing forests, buffers and other natural areas. Large lot zoning has been most frequently applied to protect drinking water reservoirs and trout streams, or generally maintain rural character.

The strength of large lot zoning is that it is relatively easy to implement in the context of existing zoning, and provides some measure of permanent protection for sensitive watersheds. The weakness is that the extensive road networks used to connect individual lots produce more IC area per dwelling unit than any other zoning category. When growth pressures are high, large lots tend to spread development over a wide geographic area and contribute to regional sprawl (U.S. EPA 2006). In addition, large lot zoning does not regulate how future property owners will manage their land, which can result in tree clearing, extensive turf or high density hobby farms. Lastly, large lot zoning obviously has no application in the more urban subwatersheds where the impacts of IC are the greatest.

Site-based IC Caps. Several communities have established IC caps within the context of a comprehensive land use plan or functional master plan for the express purpose of protecting drinking water or sensitive streams. Numerical IC caps are imposed on individual residential lots in order to stay below a designated IC threshold for the watershed as a whole. Individual development proposals are closely scrutinized to ensure the development footprint is below the IC cap, or is otherwise mitigated, disconnected or treated. For example, Montgomery County, MD has designated four sensitive watersheds as special protection areas that have an 8 to 10% IC cap for all new development (MCDEP, 2003). The strengths and weaknesses of IC caps are generally similar to those for large lot zoning. IC caps also have the added weakness that they require frequent monitoring to ensure that individual owners do not add more IC in the post-construction phase.

Watershed IC Caps. Direct watershed IC caps have been considered in a number of communities but seldom have been implemented. The caps can be used to protect both sensitive and impacted

watersheds. The main drawback is the difficulty in measuring the aggregate change in a subwatershed IC cap over time as a result of many individual zoning and development decisions. A more indirect way to implement a watershed IC cap is through the watershed-based zoning approach.

Development Intensification. Higher density development generates less runoff and pollution per capita, per household or per increment of job growth (U.S. EPA 2006). Therefore, many urban planners and smart growth advocates have suggested that density be intensified within certain subwatersheds or designated planning areas in order to reduce development pressure in sensitive subwatersheds elsewhere. Intensification often involves high rise development, parking garages, mass transit, mixed uses and other features to decrease per-capita IC creation. Intensification is often created by drawing urban growth boundaries and then using incentives and public infrastructure investments to attract redevelopment. Portland (OR) and Toronto (ONT) are two well-known examples where urban growth boundaries were used to promote intensification.

The strength of intensification is that it confers numerous social, community and economic benefits and should result in less dramatic change to stream quality if the area is already developed (e.g., shifting from non-supporting to urban drainage). The weakness of intensification is that it cannot directly protect sensitive or impacted watersheds when multiple communities are involved. At the regional scale, it is often possible for both intensification and low density sprawl to occur at the same time, in response to different market forces and consumer preferences (e.g. land prices, affordable housing, commuting distances, employment centers and the like).

Watershed-based Zoning. Watershed-based zoning is a planning technique that directly ties comprehensive planning or zoning to the ICM. Local planners evaluate current zoning within individual subwatersheds present in their community (Schueler 1994). Current and future IC are forecasted for each subwatershed as a result of buildout of existing zoning. Land is then rezoned within each subwatershed to either increase or decrease IC to achieve the desired ICM classification, which is then incorporated into the local land use master plan or comprehensive plan. The process may also involve special overlay zones that set forth more specific buffer, stormwater and land conservation requirements within each subwatershed management category. To date, several communities have directly or indirectly utilized elements of watershed-based zoning, but none have fully implemented the entire process. The primary reason has been the inherent disconnect between local watershed planning and comprehensive land use planning in most communities.

Watershed Planning. Watershed plans can guide land use decisions to change the location or quantity of IC created by new development. Numerous techniques exist to forecast future watershed impervious cover and its probable impact on the quality of aquatic resources (CWP, 1998 and MD DNR 2005). The level of control that can be achieved by watershed planning is theoretically high, but relatively few communities have aggressively exercised it. In particular, few communities have fully integrated their watershed planning efforts into their comprehensive planning and zoning process. Consequently, many watershed plans contain recommendations for implementation of watershed practices, but few substantive changes in zoning or land use decisions. Powerful consumer and market forces often drive low-density sprawl development, regardless of the recommendations of the watershed plan.

Even when land use is an explicit component of local watershed plans, these local decisions are reversible and often driven by other community concerns such as economic development, adequate infrastructure, and transportation. Schueler (1996) has explained the primary reasons why local watershed plans are not fully implemented. Many of these reasons still exist today. Consequently, many communities continue to struggle with how to influence the optimal location and intensity of subwatershed ICM in their watershed plans. Furthermore, they often lack an effective accountability mechanism (such as a watershed-based permit) to fully implement these plans.

5-A.9.2 Engineering Responses to the ICM

Traditional Stormwater Treatment Requirements. Many communities have relied on engineering rather than planning solutions to address ICM impacts. The major trend has been to adopt stormwater management requirements to treat both the quality and quantity of runoff from individual development sites. The most common practice has been to pipe runoff into a stormwater detention or retention pond. Performance research studies indicate that ponds do have modest flood control and pollutant removal capability (ASCE, 2007 and CWP 2007). Traditional stormwater ponds, however, have not been shown to improve stream quality indicator scores. For example, seven research studies have concluded that stormwater ponds are incapable of preventing the degradation of aquatic life in downstream channels (MNCPPC 2000; Maxted 1999; Stribling et al. 2001; Galli 1990; Horner and May 1999; Horner et al. 2001; Jones et al. 1996). Given that current stormwater technology cannot fully mitigate land development impacts, the engineering community has explored new sizing criteria and stormwater technology to improve their performance.

Runoff Reduction Approach. The prevailing stormwater paradigm has recently shifted to what is known as the Runoff Reduction Approach (Schueler 2008). The goal is to mimic natural systems as rain travels from the roof to the stream through combined application of a series of small practices distributed throughout the entire development site. Runoff reduction is operationally defined as the total runoff volume reduced through canopy interception, soil infiltration, evaporation, rainfall harvesting, engineered infiltration, extended filtration or evapotranspiration. The overall site design objective is to replicate the runoff coefficient for all storms up to a certain design storm event for the native predevelopment land cover.

Runoff reduction practices include rain tanks, rain gardens, infiltration, bioretention, dry swales and linear wetlands, among others. The comparative runoff reduction rate achieved by various stormwater practices varies greatly, as shown in **Table 5-A.4**. Several traditional stormwater practices, such as ponds and sand filters have little or no capability to reduce incoming stormwater runoff volume (Strecker et al. 2004), whereas other practices can achieve annual runoff reduction rates ranging from 40 to 90%, depending on their design. Typically, multiple practices are needed at each site to incrementally reduce the total stormwater runoff volume delivered to the stream. The major challenge with runoff reduction is how to size and arrange the individual practices to meet the appropriate stream protection objective with a subwatershed. The most recent approach is to define a variable runoff reduction volume based on the subwatershed management designation. The shift to runoff reduction is quite recent, so monitoring efforts to demonstrate its effect on improving stream quality indicator scores at the subwatershed scale have yet to be

completed. Several recent studies have shown that LID or runoff reduction approaches can be effective at the scale of the individual site (Phillips et al, 2003, Selbig and Bannerman, 2008).

Table 5-A.4. Comparative Runoff Volume Reduction Rates of Selected Stormwater Control Measures in the Chesapeake Bay Region

SCM	Level 1 RR ¹	Level 2 RR ¹
Infiltration	50	90
Bioretention	40	80
Soil Amendments	50	75
Permeable Pavement	45	75
Green Roof	45	60
Dry Swale	40	60
Rain Tanks/Cisterns	Actual holding volume x 0.75	
Filter Strip	25-50	50
Rooftop Disconnection	25	50
Grass Channel	10	20
Extended Detention Pond	0	15
Wet Pond	0	0
Constructed Wetland	0	0
Wet Swale (Linear Wetland)	0	0
Filters	0	0

¹ SCM Level 1 and Level 2 designs are explained in CWP/CSN (2008)

Source: CWP/CSN (2008)

Special Subwatershed Stormwater Criteria. Another approach has been to define special subwatershed design criteria that govern the size, selection and location of the structural and non-structural practices needed to protect aquatic resources in sensitive subwatersheds. Several recent state stormwater manuals have established more prescriptive criteria to protect sensitive waters, such as wetlands, lakes, and trout streams (see Wenger et al 2008 and MPCA 2005) or to focus on increasing the removal of a specific pollutant of concern in a more developed situation (see Schueler 2008).

Watershed Restoration Practices. Stormwater retrofits, stream repair, riparian and upland reforestation, discharge prevention and pollution source controls have all been applied to restore stream quality in urban subwatersheds. A full description of their strengths and weaknesses can be found in the Small Watershed Restoration Manual Series produced by the Center for Watershed Protection. The individual and aggregate effectiveness of restoration techniques appears to be inversely related to the amount of IC present in a subwatershed (Schueler 2004). The best prospects for improving stream quality indicator scores occur in sensitive and impacted watersheds, whereas the cost and feasibility of restoration climbs rapidly in non-supporting and urban drainage subwatersheds (Schueler et al. 2007).

Most communities assemble individual restoration practices within the context of a larger watershed restoration plan to achieve defined stream quality objectives. The key problem of watershed planning tends to be one of implementation. Many communities have fine plans, but have only implemented a handful of actual restoration projects. The poor track record in implementation is created by the inherent difficulty of delivering dozens or hundreds of restoration projects over time, their high cost, and the lack of dedicated financing to build them. In addition,

most local watershed restoration plans lack accountability mechanisms to ensure progress is maintained over the 10-15 years required for full implementation.

5-A.9.3 Regulatory Responses to the ICM

Beneficial uses and related water quality standards are frequently exceeded in most urban subwatersheds, so regulatory agencies continue to grapple with the ICM as it relates to the many complex provisions of the Clean Water Act. Some recent trends include the following:

Anti-Degradation, Tiered Uses and Wet Weather Standards. Several sections of the Clean Water Act could potentially protect sensitive and impacted streams, or allow greater flexibility in meeting standards in non-supporting streams. For example, anti-degradation provisions can protect waters that currently achieve or exceed water quality standards or their designated use, but are threatened by future watershed development. States such as Ohio and Maine have crafted anti-degradation rules to regulate discharges or activities by NPDES permittees in the watershed to protect healthy waters. States also have the capability to designate tiered uses and wet weather standards to set more realistic water quality goals for non-supporting and urban drainage subwatersheds, although, to date, few have exercised this option.

Impervious cover based TMDLs. Total Maximum Daily Loads or TMDLs are the primary tool to document how pollutant loads will be reduced to meet water quality standards. Maine, Vermont and Connecticut have recently issued TMDLs that are based on IC rather than individual pollutants of concern (Bellucci 2007). In an IC- based TMDL, IC is used as a surrogate for increased runoff and pollutant loads as a way to simplify the urban TMDL implementation process. IC-based TMDLs have been issued for small subwatersheds that have biological stream impairments associated with stormwater runoff but no specific pollutant listed as causing the impairment (in most cases, these subwatershed are classified as impacted according to the ICM). A specific subwatershed threshold is set for effective IC, which means IC reductions are required through removal of IC, greater stormwater treatment for new development, offsets through stormwater retrofits or other means. Since IC-based TMDLs have only appeared in the last year, communities have little or no experience in actually implementing them. Traditional pollutant-based TMDLs continue to be appropriate for non-supporting and urban drainage subwatersheds, although they could be modified to focus compliance monitoring on priority urban source areas or subwatersheds that produce the greatest pollutant loads.

Watershed-Based Permitting. U.S. EPA (2007) has issued technical guidance to promote watershed-based permitting, which has the potential to integrate the many permits to improve water quality conditions in urban watersheds. States and localities, however, have yet to implement watershed-based permitting at the sub-watershed scale in the context of the ICM. This regulatory tool shows promise, and several recommendations for applying it to urban watersheds as part of the NPDES MS4 stormwater permit program are presented in the Watershed Planning section of **Chapter 5**.

5-A.9.4 Economic Responses to the ICM

Economists have been attracted to IC because it is easy to measure and can act as a common currency that spans and transcends the site and watershed scale. In recent years, economists have tried to value or price IC so as to better use market forces to improve urban watershed management. These efforts are mostly in their infancy and face the twin problems of defining the unit price of IC and how it varies among subwatersheds with different IC. Several economic approaches that utilize IC are described below.

IC-Based Utilities. Several hundred communities have adopted stormwater utilities that charge residents and businesses a monthly or quarterly charge based on their IC. Funds are used to operate stormwater programs, maintain stormwater infrastructure and comply with their stormwater permits. Utility charges typically range from \$30 to \$120/year/ residential unit and apply only to existing development. In most cases, an average unit IC charge is applied to all homes and businesses, since most communities lack enough GIS or political resolution to estimate IC and charge for individual parcels. The utility fee can be an incentive to reduce site IC by reducing charges for homeowners that install retrofits such as rain gardens.

IC Mitigation Fees. IC mitigation fees can be applied to new development to discourage the creation of excess IC or to pay for off-site restoration when on-site stormwater compliance is not possible. In the first case, communities establish a maximum IC cap within an individual zoning category or for the subwatershed as a whole. New development projects that exceed the cap are charged a unit fee used to finance restoration practices elsewhere in the subwatershed. In the second case, an IC-based fee-in-lieu is charged when an individual site cannot meet stormwater runoff reduction requirements in full or in part. The basic IC pricing mechanism is the same in both cases: the average per IC acre cost to provide an equivalent amount of restoration or stormwater treatment elsewhere in the watershed. The weakness of mitigation fees involves difficulty in accurately matching the fees collected to actual construction of cost-effective restoration projects in the desired subwatershed that needs restoration.

Subwatershed IC Trading and Offsets. Trading of IC among subwatersheds is still a novel concept although its theoretical elements have been outlined by Parikh et al. (2005). Like other water quality trading programs, development sites that face higher pollution control costs can meet their regulatory obligations by purchasing environmentally equivalent (or superior) pollution reductions or “credits” from another subwatershed at lower cost, thus achieving the same water quality improvement at lower marginal cost. IC is a logical currency for stormwater trading, and may be most efficient in shifting costs among different subwatersheds to produce the greatest water quality improvement. For example, the higher compliance cost in an urban drainage subwatershed might be traded to a sensitive subwatershed to provide greater protection by purchasing lower cost conservation easements.

5-A.10 SUMMARY

The preceding review suggests that no single planning, engineering, economic or regulatory tool appears capable of effectively protecting or restoring stream quality over the full range of subwatershed IC. Some individual tools work reasonably effectively across a narrow range of impervious cover, but most have significant weaknesses, particularly when it comes to implementation. In addition, most communities tend to use only one kind of tool to mitigate the impact of IC (i.e. planning approaches versus engineering solutions). As a result, most communities are unsatisfied with the outcomes of their urban watershed protection or restoration efforts to date.

The review also suggests some possible management remedies. The first is that many communities set unrealistically high expectations for stream quality given their development intensity. In this instance, it may be wise to set more realistic and achievable stream quality objectives (several recommendations are made in the ensuing section. Second, communities may wish to apply a combination of planning, engineering, economic or regulatory tools at the same time. Third, communities should classify their subwatersheds to make sure they are applying the most effective and appropriate tools within the prescribed range of subwatershed IC. Lastly, communities may need to develop more stringent accountability mechanisms to ensure that the tools they use are fully implemented.

5-A.11 A SUGGESTED URBAN STREAM MANAGEMENT SYSTEM

Once realistic expectations have been set for a subwatershed, the specific combination of planning, engineering, economic and regulatory tools that are needed becomes more obvious. Some potential combinations for each subwatershed management category are detailed in **Tables 5-A.5 through 5-A.7**. It should be strongly emphasized that these strategies provide a starting point for developing a local watershed management strategy, and that they will always need to be modified for local conditions.

5-A.11.1 Management Strategies to Protect High Quality Streams

One of the more troubling findings of the ICM, and much of the recent urban stream research, is that it does not take very much subwatershed development to degrade high quality streams – depending on the ecoregion, as little as 3 to 7% IC. Many high quality streams have evolved in response to the forest (or native cover) of their subwatersheds, and have unique habitat conditions that support trout, salmon or spawning of anadromous fish. Given the vulnerability of these streams, watershed managers must commit to an aggressive protection strategy to mitigate the impacts of land development (**Table 5-A.5**). The comprehensive strategy involves watershed zoning, land conservation, preservation of the riparian network and stormwater practices that create no net increase of runoff volume or velocity up to the two year design storm event.

Additional regulatory and economic tools are also needed to protect and maintain the quality of exceptional streams, as shown in **Table 5-A.5**. While the proposed strategy is much more stringent than what most communities currently allow, it is technically achievable, and provides greater reliability in meeting the objectives of maintaining exceptional stream biodiversity and

function. From the standpoint of implementation, it is important to formally designate these subwatersheds as being exceptional, and then using the anti-degradation provisions of the Clean Water Act to provide regulatory support for the development restrictions.

Table 5-A.5. Management Strategies to Protect High-Quality Streams

Subwatershed Outcomes Need to Protect High Quality Streams
<ul style="list-style-type: none"> • Restrict subwatershed IC to less than 10% (or a regional IC threshold) • Retain more than 65% forest or native vegetative cover in the subwatershed • Ensure forest or native cover on at least 75% of the stream network • Do not allow more than one crossing per stream mile, and none that create a barrier to migration
Recommended Watershed Planning and Engineering Practices
<ul style="list-style-type: none"> • Require full runoff volume reduction up to the 2-year storm for all new IC by maximizing the use of runoff reduction practices and discouraging conventional detention ponds and large diameter storm drain pipes • Establish wide stream buffers (100-200 feet) for the entire drainage network, including zero-order streams • Apply conservation practices to all croplands and keep livestock out of streams • Use site or subwatershed IC caps, extremely large lot zoning, watershed-based zoning, farm preservation, or conservation easements to limit subwatershed IC • Use limited stream restoration to restore habitat, remove fish barriers, and correct past mistakes
Recommended Regulatory and Economic Measures
<ul style="list-style-type: none"> • Protect healthy streams using anti-degradation provisions of the Clean Water Act • Monitor the geomorphic stability and biological diversity of the streams to verify compliance • Reduce public infrastructure investments in the subwatershed to discourage growth • Increase technology and permit requirements for private water and sewer infrastructure • Designate these subwatersheds as receiving areas for IC mitigation fees to finance restoration and secure conservation easements

5-A.11.2 Management Strategies for Suburban Streams

Stream quality in suburban subwatersheds (10 to 25% IC) exhibits a great deal of variability or scatter. Indicator scores can range from poor to fair to good (but not excellent). A reasonable management objective is to achieve both good indicator scores and maximize stream function to adequately protect downstream receiving waters from degradation (e.g., flood storage, in-stream nutrient processing, biological corridors, stable stream channels, etc.). Given the relatively light development intensity of suburban watersheds, there is room to apply a broad range of management practices in the uplands and the stream corridor (**Table 5-A.6**).

The basic upland management prescription for suburban streams is to maximize tree canopy and minimize both turf and impervious cover across the subwatershed. Stormwater practices that achieve full runoff reduction up to the two year storm event are applied in a roof to stream sequence to reduce channel erosion and maintain recharge. The prescription for the stream corridor is to protect and enhance buffers around streams, wetlands and floodplains, with special emphasis on minimizing the enclosure of zero order streams (i.e., maintaining them as an open stormwater treatment system). Some elements of the stream corridors may require stream repairs, reforestation or wetland creation.

Table 5-A6 also outlines the regulatory and economic tools needed to implement and maintain watershed practices for suburban streams. The key management challenge is to prevent a gradual “creep” in IC over time through rezoning, redevelopment and homeowner expansions. Consequently, watershed managers should set clear goals for maximum future IC, and track it over time to ensure it remains within prescribed limits.

Table 5-A.6. Management Strategies to Protect Impacted Suburban Subwatersheds

Recommended Watershed Planning and Engineering Practices
<ul style="list-style-type: none"> • Require full runoff reduction up to the one year storm for all new IC created in the subwatershed • Minimize subwatershed IC, maximize forest cover and conserve soil quality using runoff reduction practices from roof to stream • Conserve and protect stream buffers, floodplains, wetlands and river corridor in a natural state and in public ownership • Adjust zoning to limit IC to meet 20 to 25% subwatershed IC caps • Use Better Site Design roundtable process (CWP, 1998a) to seek 25% reduction in average IC and turf cover produced by each zoning category • Implement selected stream restoration and storage retrofits to mitigate effect of existing development in the watershed • Establish an ultimate subwatershed tree canopy goal of 40 to 45%
Recommended Regulatory and Economic Measures
<ul style="list-style-type: none"> • Utilize IC-based TMDLs to set specific targets for runoff reduction and removal of pollutants of concern • Invest in public infrastructure to enhance the quality of drinking water, wastewater and stormwater • Designate these subwatersheds as receiving areas for IC mitigation fees to finance retrofits and other restoration practices • Impose IC mitigation fees for both new and existing development to discourage creation of needless impervious cover, finance restoration and maintain stream protection and stormwater infrastructure

5-A.11.3 Strategies to Manage Highly Urban Streams

The quality of highly urban subwatersheds will be inevitably degraded by the combination of IC creation, soil compaction and stream alteration. Highly urban streams can have one of two management designations – non-supporting (25 to 60% IC) and urban drainage (60 to 100% IC). Urban drainage subwatersheds generally have little or no remaining surface stream network, whereas non-supporting streams still have some surface streams, although they are often highly degraded and fragmented. The management goal for both stream classes is to limit the extent of degradation, while at the same recognizing these subwatersheds are an intense human habitat, both in the uplands and the remaining stream corridor. The proposed management strategies for non-supporting and urban drainage subwatersheds are presented in **Table 5-A.7**.

The basic approach is to protect public health and safety through stormwater management, pollution prevention and discharge prevention practices in the uplands, and to use the stream

corridor as a greenway and a conduit for floodwaters. While it is not possible to achieve high levels of aquatic diversity, the watershed practices can reduce pollutant export to downstream receiving waters, and ensure safe water contact during dry weather periods. The land use planning strategy for these subwatersheds encourages both intensification and redevelopment. The impacts from increased IC can be ameliorated by green buildings, expanded urban tree canopy, and selected stormwater retrofits and watershed restoration projects.

Table 5-A.7. Strategies for Non-Supporting and Urban Drainage Subwatersheds ¹

Recommended Watershed Planning and Engineering Practices
<ul style="list-style-type: none"> • Encourage intensification and redevelopment • Require runoff reduction for the 90th percentile storm as part of the redevelopment process (NS subwatersheds) or a fraction thereof (UD subwatersheds) • Provide sufficient upland retrofit, discharge prevention, and pollution prevention practices to treat stormwater hotspots • Utilize street cleaning and storm drain inlet cleanouts to remove gross pollutants from the dirtiest source areas. • Maintain a forest canopy goal of at least 25% and 15% for NS and UD subwatersheds, respectively • Manage the remaining stream corridor as a greenway and protect/restore large natural area remnants
Recommended Regulatory and Economic Measures
<ul style="list-style-type: none"> • Utilize conventional TMDLs to reduce pollutants of concern at the most polluted subwatersheds and urban source areas. • Conduct dry weather water quality monitoring in streams (NS) or receiving waters (UD) to assure progress towards goals • Designate these subwatersheds as sending areas for IC mitigation fees to finance retrofits and other restoration practices in less dense subwatersheds • Impose IC mitigation fees for redevelopment when full site compliance with runoff reduction targets cannot be attained.
<p>¹ For space purposes, the strategies for non-supporting (NS) and urban drainage (UD) have been combined together since they differ primarily in the scope or extent of treatment, except where noted</p>

For some, this strategy sacrifices urban streams, and enables municipalities to violate existing water quality standards. The key point, however, is that IC and associated infrastructure has such a dominant influence on these streams that aquatic diversity and water quality standards could never be met, regardless of the investment. Implementation of the stringent measures outlined in **Table 5-A.7** can result in incremental improvements in local waters and substantial pollutant reduction to downstream waters.

5-A.12 CONCLUSIONS

The reformulated ICM organizes and simplifies a great deal of complex stream science into a model that can be readily understood by watershed planners, stormwater engineers, water quality regulators, economists and policy makers. More information is needed to extend the ICM as a

method to classify and manage small urban watersheds and organize the optimum combination of best management practices to protect or restore streams within each subwatershed classification.

The challenge for scientists and watershed managers is no longer proving the hypothesis that increasing levels of land development will degrade stream quality along a reasonably predictable gradient – the majority of studies now support the ICM. Rather, researchers may shift to testing a hypothesis that widespread application of multiple management practices at the catchment level can improve the urban stream degradation gradient that has been repeatedly observed. The urgency for testing the catchment effect of implementing best management practices is underscored by the rapid and inexorable growth in IC across the country.

5-A.13 REFERENCES

** Denotes research papers that were included in the Center for Watershed Protection's ICM database. A list of additional papers that were reviewed, but did not meet the criteria for inclusion in the ICM database, is available upon request from the Center for Watershed Protection.*

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